New Scientist

18/25 December 2021

YEAR IN REVIEW

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Three missions to Mars
DeepMind folds proteins
Extraordinary weather
Climate action, finally?
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Cover image: Brett Ryder

Welcome, dear readers, to this bumper edition of the magazine, packed full of puzzles, snowflakes, animal magic and many other treats. We do hope you enjoy it.

This has been a long pandemic and it isn't going to be over any time soon. But on behalf of everyone at *New Scientist*, I do wish you a wonderful holiday season and a happy (and healthy) new year.

Science has played a blinder over the past two years. Here's to more of the same in 2022!

Emily Wilson
New Scientist editor

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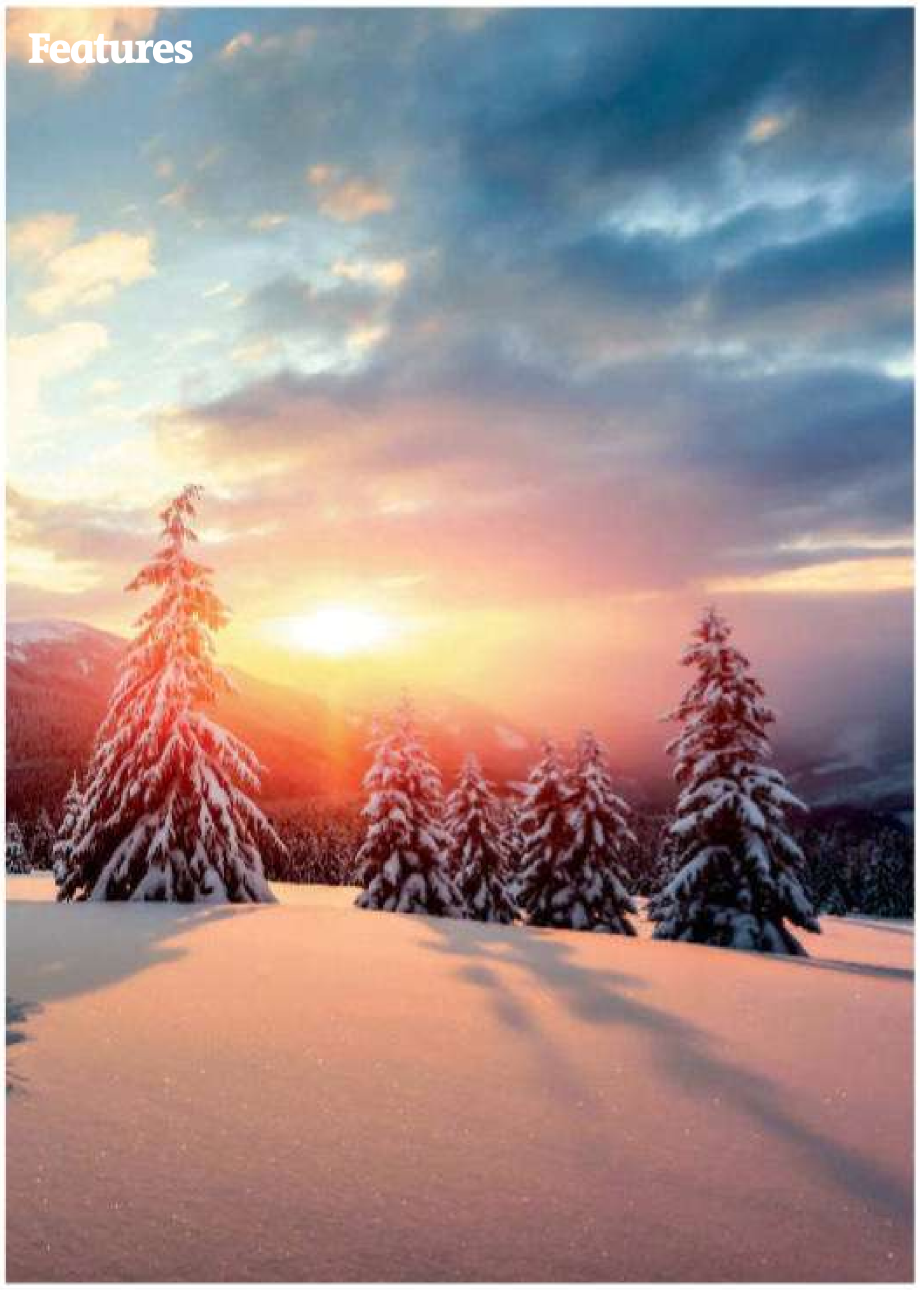

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New Scientist Live

Our mind-blowing festival of ideas is returning to the stage in a new venue, combining the best of in-person and virtual experiences. We will welcome more than 9000 visitors, 40 speakers and 30 exhibitors in person for talks and hands-on demonstrations. Join us from 12 to 14 March 2022 at Manchester Central, UK. The first two days are open to all, with the final day dedicated to schools and home learners. Find out more about what's happening online:

live.newscientist.com

Video

What's so funny?

To find out, we visited Laughter Lab, an exhibition and social experiment at London's Cartoon Museum. The exhibition explores our reaction to humour, showcasing a wide selection of cartoonists. Don't forget to subscribe to our channel for more great videos:

youtube.com/newscientist

ERIC BACCEGA/NATUREPL

Podcast

Weekly

The team discusses why the omicron coronavirus variant might dodge immunity; climate journalist Emily Atkin drops in to chat about new Netflix satire *Don't Look Up*, about two astronomers' attempts to warn humanity of an approaching comet; and Steven Pinker talks about his new book *Rationality*. Plus: the bubbling sounds of melting glaciers and news of a GPS-like navigation system that uses cosmic rays to orient itself.

newscientist.com/nspod

PALLADIUM CHALLENGE CONTEST

Nornickel, the world's largest producer of palladium and high-grade nickel and a major producer of platinum and copper, announces the start of the Palladium Challenge, a contest with a USD 350,000 prize fund organised in partnership with the International Precious Metals Institute (IPMI).

The Palladium Challenge is an initiative intended to inspire individuals, businesses and academic institutions to invent and design a sustainable use-case that features and increases the demand for palladium. The metal is known for its catalytic capabilities and unique physical properties, and while it is widely used in the automotive industry as an essential component of catalytic conversion, the Palladium Challenge seeks to broaden its applications and spark innovation.

The Palladium Challenge will be judged by an independent panel of global experts who will review all submissions.

The **top three projects** will receive global recognition and **will be awarded monetary prizes on September 16, 2022** at the IPMI Annual Platinum Dinner in New York City.

THE PRIZES WILL BE AS FOLLOWS:

1st Place:
USD 200,000

2nd Place:
USD 100,000

3rd Place:
USD 50,000

Registrations are now open on the IPMI website **https://ipmi. corgano.com.** Completed proposals must be submitted no later than May 31, 2022.

All entries are subject to the Official Rules of the Palladium Challenge.

A spark of light

Climate change and covid-19 dominated 2021, but there is cause for rational optimism

REINHARD DIRSCHERL/ULLSTEIN BILD VIA GETTY IMAGES

"A YEAR of tackling great challenges." In the title of our review of the year (see page 21), "tackling" is the operative word. Two great challenges have dominated the past 12 months: the ongoing covid-19 pandemic, and efforts to address climate change, as embodied by the COP26 summit held in Glasgow, UK, in November. Both have seen significant progress – but only the most irrational optimist could claim that what we have achieved so far amounts to solutions.

Our retrospective leader of 2020 was devoted to the promise that vaccines might bring a swift end to covid-19. At the time, more than 70 million people had fallen ill with the virus, and according to (undoubtedly conservative) quasi-official estimates, 1.5 million had died. Today, those figures stand at almost 270 million and over 5 million. The world looks to be entering a significant fourth wave.

It could have been so much worse. Vaccines have indeed been a triumph in terms of lives saved and serious health consequences averted, for those who have received them (see page 22). Looking to the future, the success of mRNA vaccines should lead to many more jabs against other diseases, and also to a whole new kind of treatment for all sorts of conditions that uses mRNA technology to get our bodies to make therapeutic proteins.

That justifies the three rousing cheers for science that we allowed ourselves last year. But in terms of ending the pandemic, the vaccine-boosted optimism of the early part of the year has been undone by many factors, not least evolution doing what evolution does. The predictable emergence of new, more transmissible variants has complicated things, and new variants could well keep emerging indefinitely (see page 8), although as the world's collective immune system builds strength against SARS-CoV-2 over the years to come, new emergences should cause less disruption.

What remains true is that vaccination is our best protection. This makes tackling sources of vaccine scepticism and hesitancy more vital than ever. It also means that a great failure of the past year, to distribute doses equitably across the globe based on need rather than nationality, must be addressed with urgency.

Global inequities also made for an uncomfortable backdrop to COP26 (see pages 29 and 34). The failure of higher-income countries to come up with $100 billion of finance a year for lower-income nations to mitigate the effects of climate change was a source of bad blood in the run-up to and during the summit.

And yet the political penny seems – finally – to have dropped on climate. That was driven in no small measure by extreme weather events, from the "heat dome" over the western US and Canada to wildfires in Greece and Turkey to flooding in Germany and China, hammering home that climate change is here and its effects are real (see page 30). All the talk from leaders in Glasgow was of "following the science". While a huge gulf remains between political action and what science says is needed to limit global warming to 1.5°C, COP26 at least provided progress on issues such as "phasing down" fossil fuels, getting to grips with methane emissions and financing not just mitigation of climate change, but adaptation to its impacts.

Climate change is admittedly only one of three great environmental challenges we face, alongside biodiversity loss, and chemical waste and pollution. All three are interlinked – and appear to be connected to the emergence of pandemics, if, as seems likely, it was our exploitation of wildlife that left the door open to covid-19.

The momentum that now exists for addressing climate change must be leveraged to acknowledge and tackle a general crisis of nature. One big omission at COP26 was to recognise the importance of "nature-based solutions", chief among them protecting and expanding forests and seagrass fields – in mitigating climate change. The COP15 summit on biodiversity, the second phase of which is to be held in Kunming, China, in April and May 2022, provides an opportunity to address that omission and to start finding joined-up solutions.

Of course, it hasn't all been pandemic and environmental crisis. Another headline-grabbing story, the space race between billionaires (see page 24), drew mixed feelings. For some, it was a feat of derring-do; for others, it highlighted inequalities here on Earth.

> **"The momentum for addressing climate change must be leveraged to tackle a general crisis of nature"**

Space exploration remains a great frontier for human ambition, and as ever we can salute the ingenuity that brought three missions to Mars this year (see page 26) or indeed launched (successfully, we hope, as these words pass for press) the world's most powerful space telescope, the James Webb Space Telescope, into orbit.

Here, too, we shouldn't allow hubris to become our nemesis. With a view to the challenges we have created on Earth, we should be mindful not just of the advances, but of the challenges that the commercial exploration and exploitation of space bring – for example in the light pollution and dangers of space junk that planned megaconstellations of satellites may cause.

The world and what lies in it and beyond it remain sources of great wonder. If there is anything that the past year has taught us, it is that there are grounds for rational optimism. Solutions to our problems exist, and a better, healthier world that works for one and all is possible – but only if we work together to find common solutions, guided by science. ▮

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Robot arm learns to play in just 90 minutes **p13**

Prehistoric pace
Fossil footprints reveal speedy dinosaurs **p13**

MORTEZA NIKOUBAZL/NURPHOTO VIA GETTY IMAGES

A shop window in Tehran, Iran, on 11 December

Covid-19

A difficult Christmas

Facing a festive season dominated by omicron, few countries appear to have substantially changed their plans, reports **Michael Le Page**

THERE now seems little doubt that the Christmas period will coincide with another major wave of coronavirus cases around the world, as it becomes clear that the omicron variant can largely evade prior immunity from infection or two vaccine doses, and might be even more transmissible than the delta variant. In England and Scotland, cases have been doubling every two days. The big unknown remains whether there will be as many hospitalisations and deaths as in previous waves.

In South Africa, the country that first detected omicron, the variant has spread far faster than earlier variants, with cases doubling every three to four days.

As *New Scientist* went to press, there was confusion – due to IT issues – about whether case numbers in South Africa were now slowing or still accelerating. But in Gauteng province, nearly as many cases have already been reported as during the country's delta wave earlier this year.

Initial reports suggest there have been fewer hospitalisations and deaths in South Africa than during previous waves, but it is too early to be sure. Furthermore, it is estimated that almost everyone in the country had already been infected or vaccinated before omicron began to spread, so prior immunity – although usually insufficient to prevent infection – would be expected to greatly reduce the risk of severe disease.

Outside South Africa, the UK and Denmark have so far reported the most confirmed cases of omicron, prompting Israel to plan to ban travel to these nations on top of other travel restrictions it has already imposed.

Yet the high case numbers may largely reflect the fact that the two countries do far more sequencing than most others. Sequencing the viral genome remains the only way to confirm which variant has infected someone, though PCR tests can sometimes give an indication too. The UK would be expected to have more omicron cases than other nations because of its strong travel links to South Africa, but there is no reason to think Denmark is exceptional.

"Omicron is already everywhere," Hans Kluge at the World Health Organization said on 7 December. The many travel bans imposed because of the variant – largely on southern African countries – wouldn't work for this reason, he said.

So far, it appears only a few countries have introduced measures to prevent omicron's spread within their borders, though some, including Germany and Belgium, already had restrictions in place to tackle high numbers of delta cases.

Home working for those who can has been reintroduced across the UK, but when *New Scientist* went to press, large events would probably still go ahead in England for those with vaccine passports. This is despite UK data suggesting that being double vaccinated offers little protection from symptomatic infection with omicron.

Denmark has imposed similar measures, limiting opening hours for bars but not closing them altogether.

While most other nations have yet to impose new restrictions due to omicron, some are stepping up efforts to give booster shots to people who have already had two vaccine doses. On 12 December, Anthony Fauci, the chief medical adviser to the US president, urged those already vaccinated to get a booster shot, citing evidence suggesting it greatly increases protection against omicron.

The same day, UK prime minister Boris Johnson announced a mass booster campaign, saying "Do not make the mistake of thinking omicron can't hurt you, can't make you and your loved ones seriously ill." ▮

Coronavirus

Stopping coronavirus variants

We failed to prevent the emergence of omicron, but there are things we can do to halt the evolution of more variants, reports **Michael Le Page**

WE ARE witnessing the scenario that many people feared unfold before our eyes. The new omicron variant of the coronavirus can largely evade prior immunity and is spreading with alarming rapidity.

And the really bad news is that there is every reason to think more dangerous variants will emerge in the future. So is there anything we can do to prevent this, or at least to slow the process?

"There is absolutely something that can be done," says Aris Katzourakis at the University of Oxford.

What needs doing depends on how variants arise, and there are several potential pathways. The first is that the coronavirus can gradually acquire mutations as it spreads from one person to another. This is how the beta and delta variants formed.

In this case, we need to do all we can to keep transmission as low as possible. For starters, that means vaccinating as many people as possible, perhaps with updated vaccines. "Will fully vaccinating everyone reduce the chance of new variants?" says Katzourakis. "I would say almost certainly yes."

Other measures, such as mask mandates and better ventilation in buildings, will be required, too.

Unfortunately, all this might not prevent variants such as alpha and omicron forming. Both seemed to appear out of nowhere with a whole bunch of mutations. It is possible they evolved undetected in a region without genetic surveillance capabilities, but it is more likely that each evolved over a period of months in an immunocompromised individual.

If that is the case for the omicron variant, that would undercut the suggestion made by many – including the head of the World Health Organization – that it arose because of the failure to distribute vaccines fairly.

THIAGO PRUDENCIO/SOPA IMAGES/SHUTTERSTOCK

Halting the spread of covid-19 is the best way to combat new variants

> **"Will fully vaccinating everyone reduce the chance of new variants? I would say yes"**

An illustration of the delta coronavirus variant

SHUTTERSTOCK/FIT ZTUDIO

"It's uncertain whether vaccination would have prevented this," says Deepti Gurdasani at Queen Mary University of London. "I think global equity is vitally important. But I don't think there's necessarily a causal link."

What we do need to do is to ensure that people who are immunocompromised get at least three vaccine doses, and that those who are HIV positive are getting effective treatment, which ensures they get as much protection from vaccination as anyone else. This is the right thing to do anyway, says Katzourakis, quite apart from combating new variants.

With omicron, it is also possible that the virus jumped to other animals, mutated and then jumped back to people, a phenomenon known as reverse zoonosis. Omicron has some mutations thought to be linked to adaptation to rodents.

Vivek Kapur at Pennsylvania State University, whose team recently found "gobsmacking" levels of SARS-CoV-2 in deer in the US, thinks it is likely that the virus is circulating undetected in other species, too. You cannot even begin to work out how to prevent spill-back from animal reservoirs if you don't even know they exist, he says.

There might be another, rather surprising way that a variant could suddenly acquire a whole lot of mutations: it could happen in someone being treated with certain drugs. Some virologists think there is a risk with antiviral medication molnupiravir – which is meant to work by inducing so many viral mutations it kills the virus – and that it should be withdrawn.

Finally, in people infected with two viruses at once, there is the possibility of SARS-CoV-2 variants recombining with each other or with other human coronaviruses. There is great scepticism about a claim that omicron acquired one of its mutations this way, but there is evidence of recombination between SARS-CoV-2 variants.

The fewer people that are infected, the lower the chances are of this happening, so measures for minimising transmission will also reduce the risk of recombination. Indeed, however new variants arise, says Katzourakis, if we make it as hard for the virus to spread as possible, they may fizzle out rather than taking off.

What is clear is that none of this will be easy. Several countries that were previously successful in fighting off the coronavirus, such as New Zealand, have been struggling to control delta, let alone omicron. But if we don't do more, we will soon end up battling rho, sigma and then upsilon. We might not be able to prevent that entirely, but we can at least buy more ourselves time. ■

Environment

Race to start commercial deep-sea mining endangers ecosystems

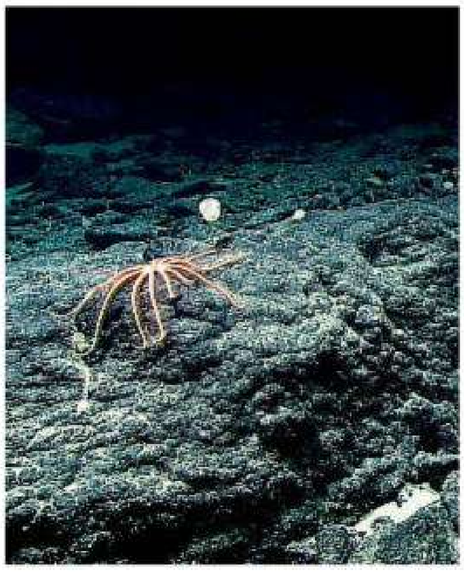
Adam Vaughan

GOVERNMENTS met in Jamaica last week to decide on the path towards a controversial new era of commercial deep-sea mining.

Advocates say tapping mineral-rich, potato-sized nodules on the ocean floor will be essential to meet the rising global demand for metals in electric cars and other low-carbon technologies, claiming it would cause less environmental harm than land-based mining. Critics say it will be devastating for marine life and habitats, and would happen alongside conventional mining rather than displacing it.

The UN regulator on the issue, the International Seabed Authority (ISA), has awarded more than 20 contracts for deep-sea mining research. But progress on rules for commercial mining, known as the mining code, has been slow since talks began in 2016. That changed in July, when the Pacific island of Nauru forced the issue.

In partnership with a Canadian mining firm, The Metals Company, Nauru invoked a clause under a UN treaty that triggers a "two-year rule". It effectively means the ISA must draw up the mining code by 9 July 2023, at which point entities can obtain licences to start commercial exploitation. The Metals Company told investors that it hopes to start "small-scale production" in 2024, across the Pacific seabed between Hawaii and Mexico.


NOAA OFFICE OF OCEAN EXPLORATION

Manganese nodules on the floor of the central Pacific basin

Governments agreed a road map on 10 December that sets out meeting dates to work on the mining code throughout next year, starting in February. One meeting scheduled to start in October will discuss a "what if" scenario if it looks like there could be no rules agreed by July 2023.

Helen Scales, a marine biologist and author, says two years isn't long enough to draw up a robust code. She wants to see a moratorium on deep-sea mining. "Nobody knows with any kind of certainty how we could go ahead extracting and exploiting these deposits in the deep sea without environmental harm," she says. "All of the science we have so far is pointing towards significant long-term and largely irreversible damage." This could stem directly from machines extracting nodules and from plumes of sediment generated by mining.

The Metals Company has conceded to investors that "it's impossible to guarantee zero loss of biodiversity" from its operations, because of imperfect baseline surveys of "wonderful and fascinating creatures".

There are sticking points on the regulations that go beyond environmental concerns. One big issue is the size of royalties from commercial mining owed to all 167 of the ISA's member countries, given that seabeds outside of national waters are considered a "global commons" for the world. Another sensitive issue is compensation. A group of African countries has said it wants rules on compensation for any losses faced by land-based miners within their borders.

> "All of the science we have so far is pointing towards long-term and largely irreversible damage"

There is one more hurdle that could trip up the start of commercial deep-sea mining: whether private sector firms can finance the first projects. Since being listed on the NASDAQ stock exchange in September, The Metals Company's share price has fallen from around $10 to about $2, and it has failed to attract as much investment as it hoped. The firm didn't respond to a request for comment. ▮

Animal behaviour

Turkey plumage colour correlates with bird fearfulness

THE feather colours of certain kinds of turkeys can predict how they will cope with life on the farm.

Raised for their meat and eggs, domesticated turkeys (*Meleagris gallopavo*) in Nigeria are born with either black, white or lavender – also called bronze – plumes.

Samuel Durosaro at the Federal University of Agriculture, Abeokuta, in Nigeria, and his colleagues ran fearfulness tests on 75 turkey chicks. The animals all came from the same genetic line and included 13 males and 12 females of each colour.

For some fearfulness tests – in which, for instance, the birds were held upside down by their legs and the amount they flapped their wings was recorded – plumage and leg colour didn't seem to make any difference.

However, for one test – in which birds were placed in a dark box with one small exit hole – the black turkeys were five times as fast as the white and lavender birds to escape. This suggests that black birds are bolder and less fearful, says Durosaro.

YVES LANCEAU/NATUREPL

A turkey (*Meleagris gallopavo*) with black plumage

And in another test, in which the researchers placed the birds one by one in a large open box, the black turkeys showed boldness by exploring more regions of the box than the lavender turkeys. White turkeys explored slightly more than either black or lavender birds. But, overall, black birds appeared to be the boldest, and attempted to escape from the box seven times more often than other birds (*Applied Animal Behaviour Science*, doi.org/g8v8).

The differences may be related to accidental side effects of domestication in combination with genetics, says Durosaro, and could guide farmers to customise their management techniques to the particular needs of the differently coloured turkeys. ▮

Christa Lesté-Lasserre

Artificial intelligence

AI reads the boring terms and conditions so you don't have to

Chris Stokel-Walker

ALMOST no one reads the long and complicated terms and conditions found on websites and apps, but now an artificial intelligence can pick out the important bits for you.

Jason Hong at Carnegie Mellon University in Pennsylvania and his colleagues trained a machine-learning model to highlight important clauses that users may want to pay attention to.

To do this, the researchers first took 1551 terms and conditions (T&C) statements from 27 shopping websites. They then split the documents into more than 200,000 pairs of sentences.

The team asked people to look at a pair of sentences and rank which was most important, using the results to rank the statements in the whole document in order of importance. Participants picked out terms defining consumer rights, along with the ability to get refunds or buy items on credit. Any fees were also deemed useful to know.

The researchers then fed this list to a machine-learning model, training it to look for important clauses. The AI was 92 per cent accurate at highlighting important statements in new T&C texts it was given (arxiv.org/abs/2111.12182).

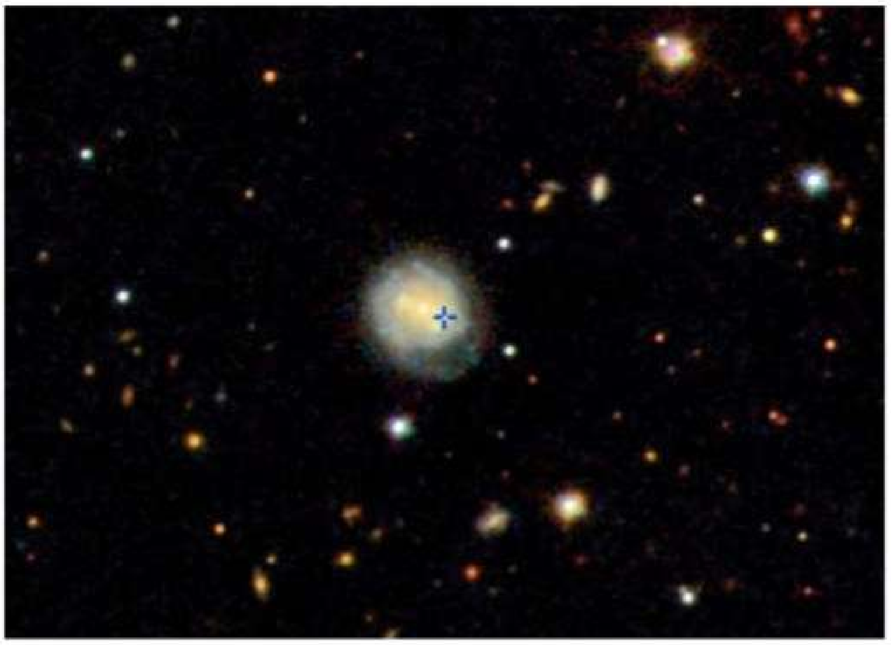
However, it tripped up on sentences using the word "not", says Hong. "If they say something like, 'We will not charge you for refunds' versus, 'We will charge you', those tend to often get classified the same, unfortunately," he says.

Lilian Edwards at Newcastle University, UK, argues that making T&C texts more readable doesn't solve the main issue: they are so dictatorial that "meaningful consent online in the consumer context does not exist", she says. "Rather than trying to highlight 'important' phrases to be wary of, we should be asking for better rights for users." ▮

Astronomy

'Space cow' explosion was probably a failed supernova

Leah Crane



SLOAN DIGITAL SKY SURVEY

A 2018 blast was labelled AT2018cow and nicknamed "the Cow"

AN EXPLOSION that baffled astronomers in 2018 may finally have an explanation. Observations of X-rays from the blast have revealed that it was probably a massive star that only partially blew up, leaving behind either a dense neutron star or a small black hole – something we have long suspected happens, but never seen until now.

When astronomers spotted AT2018cow – nicknamed "the Cow" because of the chance order of the letters in its official designation – it took only days to reach its peak brightness. Most supernovae take weeks or months to reach their peaks. It was also 10 to 100 times brighter than typical supernovae.

That made it difficult to explain. "This sudden blip out in space was really unusual, and we don't see many of these. This is the nearest by and the best studied," says Kate Maguire at Trinity College Dublin in Ireland, part of the team that discovered it.

It was so unusual that astronomers around the world immediately started observing it. "We watch stars explode all the time – supernovae are very common now, and there are lots of what are ultimately fairly minor differences – but it's really rare that you look at something and just say, 'I have no idea what this is'," says Daniel Perley at Liverpool John Moores University in the UK. "There were so many things that made it weird."

Luckily, because the Cow is relatively nearby, at about 195 million light years away, it was possible to use various telescopes to observe it in different wavelengths of light. Dheeraj Pasham at the Massachusetts Institute of Technology and his colleagues used the Neutron Star Interior Composition Explorer (NICER) space telescope to capture the X-rays coming from the explosion's aftermath over a period of about two months.

195m
Distance in light years to the Cow from Earth

They found that the strength of this radiation oscillated up and down every 4.4 milliseconds.

As a general rule, the speed of oscillation of light coming from an object in space is proportional to its size, so the researchers calculated that the object at the centre of the Cow must be no more than 1300 kilometres across (*Nature Astronomy*, DOI: 10.1038/s41550-021-01524-8).

That means that it had to be a neutron star or a relatively small black hole, referred to as compact objects. "People have been suspecting that these kinds of extreme explosions could be the birth of black holes or neutron stars, but this is a final piece of evidence that I think really settles the case," says Pasham.

The object at the centre of the Cow could be either, but it is harder to find a neutron star model that fits as the oscillation of light is steady. "In most neutron star models, you wouldn't expect it to be steady," says Perley. "Other observations about this object also point towards it being a black hole."

Combining this work with other data from the Cow suggests that the object probably formed after a failed supernova in which some of the material exploded and some fell back in on itself.

Regardless of which type of compact object lies at the heart of the Cow, the fact that we spotted it days after the explosion is a big deal, says Pasham. "When you go to school, you learn that when stars explode, black holes and neutron stars are born, but nobody has actually detected a compact object immediately after a supernova," he says. ▮

AN IMPORTANT MESSAGE FROM PROFESSOR NICK LEMOINE MD PHD FMEDSCI, CHAIR OF THE MEDICAL RESEARCH FOUNDATION

Gifts in Wills could be the key to protecting the future of human health

Our experience of COVID-19 shows how suddenly a global health challenge can appear. As someone interested in science, you will understand that while nobody can predict what we will face next, we can be certain that the future will bring many more threats to human health.

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"The funding I received through the Medical Research Foundation will be transformative for my research." Dr Myrsini Kaforou

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Professor Nick Lemoine MD PhD FMedSci
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Space

Black hole telescope launched

The Imaging X-ray Polarimetry Explorer will probe the universe's most exotic objects

Will Gater

NASA and the Italian Space Agency have launched an X-ray-observing mission that will give astronomers an important new tool for studying energetic objects across the universe.

The Imaging X-ray Polarimetry Explorer (IXPE) rode into orbit on a SpaceX Falcon 9 rocket from Cape Canaveral, Florida, on 9 December. It will measure the polarisation of X-ray light coming from objects including neutron stars, black holes and the glowing leftovers of exploded stars, known as supernovae remnants.

Polarisation can be thought of as a collective orientation of the electromagnetic waves that make up light. Studying this aspect of the X-ray glow from astronomical bodies can help researchers refine their models of the physics at work in those objects.

"Each [theoretical] model of any of these [X-ray] sources has a peculiar expected signature in polarisation and measuring it would allow us to [identify] the correct model," explains Fabio Muleri at Italy's National Institute for Astrophysics, who works on the IXPE project.

Polarisation data can also provide clues about the physical characteristics of distant objects. For example, it can reveal if an X-ray-emitting object has an asymmetrical shape – such as a swirling disc of superheated material around a black hole or neutron star.

"Measurements of polarisation give us the opportunity to study the asymmetry of the system even when the source is too far, or too small, to be resolved with our telescopes," says Muleri.

An artist's impression of the new IXPE space observatory in orbit

NASA

The mission's targets for further study include the immense "relativistic" jets of matter blasted out from black holes at close to the speed of light. The IXPE observations should give researchers a detailed insight into the magnetic fields and particles within these jets, says Ziri Younsi at University College London.

"This information will be important in understanding the genesis and structural composition of relativistic jets, as well as helping to clarify more precisely how black holes power and launch these [jets] across such vast distances," he says.

Supernovae remnants are another type of object that IXPE will investigate. Astronomers think these glowing clouds of material – permeated by violent shock waves from the detonation of a star – are responsible for producing high-energy particles called cosmic rays.

"These are believed to be important to heating up gas in the cosmos," says Mikako Matsuura at Cardiff University in the UK. "Polarisation imaging in the X-ray wavelengths will capture exactly how the particles are accelerated in supernova remnants."

The prospect of starting to resolve enduring astrophysical mysteries is already generating excitement. "Over [the years], we accumulated many expectations based on our current knowledge that we now will be able to confirm or disprove," says Muleri. ▮

Child development

Mother's scent helps babies bond with strangers

BABIES are more socially receptive to unfamiliar women when they can smell their mother's natural body odour, suggesting that maternal scent functions as a safety signal.

Previous research has found that mothers' unique smell signatures allow their babies to recognise them and have a soothing effect when they are in pain. Yaara Endevelt-Shapira at The Interdisciplinary Center in Herzliya, Israel, and her colleagues wondered if signals in maternal odour also change the way infants respond to strangers.

They asked 62 mothers to wear cotton T-shirts for two consecutive nights and avoid using deodorant or other scented products, so that their natural smell would rub off onto the clothing. Their babies – aged 7 months on average – were then strapped into chairs and introduced to an unfamiliar woman who was about the same age as their mother, lived in the same area and was a mother herself.

When the babies had their mother's T-shirt under their nose, they were more likely to smile, laugh and gaze at the stranger than if they were sniffing an identical unworn T-shirt (*Science Advances*, doi.org/g8xm).

Electroencephalography (EEG) devices fitted to both participants' heads showed that the babies' brainwaves were also more likely to synchronise with the stranger's when they could smell their mother's T-shirt. The same kind of synchronisation is seen in babies and their mothers when they gaze at each other and is thought to be a sign of feeling mutual connection.

"Maternal body odours can assist infants in transitioning to social groups"

The findings suggest that "maternal body odours can assist infants in transitioning to social groups, exploring new environments and communicating with unfamiliar partners", says Endevelt-Shapira.

The researchers didn't look at whether the scent of fathers or other familiar caregivers can have a similar effect, but are currently investigating this. ▮

Alice Klein

Technology

Robot learns to play table tennis in just 1.5 hours

Chris Stokel-Walker

A TABLE TENNIS-playing robot can keep up a rally against humans, but like many amateur players, it struggles when attempting fancier shots.

Yapeng Gao, Jonas Tebbe and Andreas Zell at the University of Tübingen in Germany designed a computer simulation in which a virtual robot arm equipped with a table tennis racket attempted to return ping pong balls across a virtual table tennis table.

The researchers ran this simulation so that a machine learning algorithm could work out how the velocity and orientation of the racket affects the path the ball takes.

Once this algorithm, which learns by trial and error, could reliably return the ball, the researchers set it up to control the movement of a real robot arm positioned next to a table (pictured).

The system used two cameras to track the location of the real ball every 7 milliseconds, and the algorithm processed the signals and decided where to move the robotic arm to hit and return the ball.

The signals that the algorithm sent allowed the robot arm to accurately play shots to within an average of 24.9 centimetres of the intended location. This accuracy level was slightly worse than when the algorithm was working with a simulation – a common occurrence, says Tebbe, as computer simulations can't accurately represent everything in the physical world.

This robot arm can play table tennis as well as a regular human player

GAO, TEBBE, AND ZELL. 2021.

The entire process – including training in the virtual simulation and in the real world – took just 1.5 hours, demonstrating how rapidly algorithms can learn to perform in a new situation (arxiv.org/abs/2109.03100).

However, although the robot performed well against human players, it was tripped up by fast shots – and, surprisingly, by slow ones. "If a ball is slow, the robot needs to generate more speed," says Tebbe. It struggled to do that, and the ball often slumped off the racket.

"By training the system for a relatively short period of time the robot is able to cope well with differences in serve, and capable of returning using a random policy," says Jonathan Aitken at the University of Sheffield in the UK, who wasn't involved in the study.

Aitken is surprised the algorithm flunked returning slow shots. He also finds it interesting that it sometimes struggled with making shots because of the mechanical limitations of the robot system, rather than because of shortcomings with the algorithm.

The robot arm has other limitations. For instance, it struggles to play backspin shots, says Zell, because it is unable to hold the racket at the required angle needed to perform such shots. But despite these issues, he believes the robot is a good player.

"It's not worse than a regular human player," he says. "It's already on par with me."

Palaeontology

Some dinosaurs could run at 45 km per hour

Carissa Wong

ABOUT 100 million years ago in what is now northern Spain, dinosaurs reached running speeds of up to 45 kilometres per hour, making them among the fastest known dinosaurs. The conclusion comes from an analysis of fossil footprint tracks.

A few three-toed dinosaur footprints were discovered at the site in La Rioja some 35 years ago. Now, further excavations at the site have revealed more prints. In total, there are five footprints forming one short trail, and a second trail of seven footprints.

The trails were made by two medium-sized dinosaurs, each about 2 metres tall and 4 to 5 metres long, that may have belonged to either the spinosaur or carcharodontosaur family of predatory theropods.

Angélica Torices at the University of La Rioja and her colleagues analysed the distance between consecutive footprints made by the same leg, or the stride length. They then plugged the information into equations previously shown to describe the relationship between stride length and speed across a range of vertebrates, including humans.

5 metres

Estimated body length of the fast-running predatory dinosaurs

This revealed that the dinosaurs were among the fastest we know. The first track was made by a dinosaur that gradually accelerated to speeds of 37 kilometres per hour, while the second reptile was moving at up to 45 kilometres per hour with abrupt changes in speed, suggesting it switched directions as it ran (*Scientific Reports*, doi.org/g8s6).

PABLO NAVARRO-LORBÉS

A footprint left by a dinosaur moving at high speed, found in Spain

The fastest dinosaurs, most of which belonged to a group of ostrich-like animals called the ornithomimids, are thought to have reached top speeds of about 48 kilometres per hour.

The newly discovered tracks offer a rare insight, as most fossilised dinosaur footprints are made by walking, rather than running, dinosaurs.

"High-velocity trackways are very scarce around the world," says Torices. But recent findings are changing the image of dinosaurs from just walkers to very good runners, she adds.

In line with previous discoveries, this study shows that the fastest dinosaurs were medium-sized animals, says John Hutchinson at the Royal Veterinary College in the UK.

When the researchers looked more closely at the estimated speeds between consecutive footprints, they found evidence that the second track was produced by an agile dinosaur that could suddenly reduce its speed before rapidly moving on.

The dinosaurs may have been pursuing prey such as iguanodon, a horny-beaked herbivorous dinosaur, says Torices.

Cancer research

More than half of cancer biology lab findings cannot be replicated

Clare Wilson

AP/SHUTTERSTOCK

An immunotherapy researcher working in a laboratory

A LONG investigation into the reliability of preclinical cancer biology research has found that fewer than half of the results published in 23 highly cited papers could be successfully reproduced.

Tim Errington at the Center for Open Science in Virginia, which conducted the investigation, says the original plan was to reproduce 193 experiments from 53 papers. However, this was reduced to 50 experiments from 23 papers.

"Just trying to understand what was done and reported in the papers in order to do it again was really hard. We couldn't get access to the information," he says.

The 50 experiments included 112 potentially replicable binary "success or failure" outcomes. But Errington and his colleagues could replicate the results of only 51 of these – or 46 per cent (*eLife*, doi.org/g8tc, doi.org/gnp846).

The experiments were all in-vitro or animal-based preclinical cancer biology studies, and didn't include genomic or proteomic experiments. They were from papers published between 2010 and 2012 and were selected because they were all "high-impact" studies that had been read and heavily cited by researchers.

"Just trying to understand what was done and reported in papers to do it again was really hard"

The findings of the eight-year investigation align with earlier reports from pharmaceutical companies Bayer and Amgen. C. Glenn Begley was a cancer biologist at Amgen and an author of its report, published in 2012. "We looked back at the papers that we had relied upon at Amgen and found that we could only reproduce 11 per cent of the studies," says Begley.

The Amgen report was applauded by some in the research community for shining a light on an important problem. But Begley says it was also criticised for a lack of openness about which studies it tried and failed to replicate.

This criticism can't be levelled at the new investigation. Errington and his colleagues have published all the data about the studies they included. They also invited peer review of their methods before the study ended.

The investigation focused on preclinical studies, but the problems it uncovered might help explain issues with later-stage studies in people too. A previous survey showed that less than 30 per cent of phase II and less than 50 per cent of phase III cancer drug trials succeed.

There are signs of change on the horizon. The US National Institutes of Health is instituting a new policy in early 2023 that will make data sharing the default for the many projects it funds. Several journals have also changed their publishing systems in recent years to encourage open science and data sharing. ▮

Climate change

Hudson Bay polar bears lack sea ice for hunting seals

AN EXTREME lack of sea ice in Canada's Hudson Bay this winter should serve as a "wake-up call" for the risk climate change poses to polar bears, say conservationists.

Ice normally starts building up across Hudson Bay in early November, but the area remained almost entirely ice-free in the face of temperatures 6°C above average.

In the north-western part of the bay, ice extent was at a record low at the end of November, with just 13 per cent of the area covered in ice – although the US National Snow and Ice Data Center says the bay will eventually freeze.

In an average year, 70 to 80 per cent of this part of the bay is covered in ice by the end of November, which gives the polar bears the conditions they need to hunt for seals.

"It's very unusual. It's very low," says Brandon Laforest at WWF Canada. "I don't think this is panic and everything is collapsing, but it's indicative of the broader trend [of sea ice loss]."

Climate change has driven Arctic sea ice to decline at about 13 per cent per decade.

"It's not good [for the bears]," says Peter Convey, an ecologist at the British Antarctic Survey. "It tips the balance towards stress-related mortality. Fewer will survive."

CRITTERBIZ/SHUTTERSTOCK

A polar bear near Churchill, Manitoba, on the west shore of Hudson Bay

Laforest says that while bears in the high Arctic are currently doing fine, the sub-population in the Hudson Bay area are the canaries in the coal mine.

"They are the first to go through these broad implications of climate change," he says. "It's a wake-up call."

Laforest says there may be more human-wildlife conflict as hungry bears wander into Inuit communities in search of food.

The late ice is also affecting people in the region, he says, because they cannot access their usual hunting grounds. ▮

Adam Vaughan

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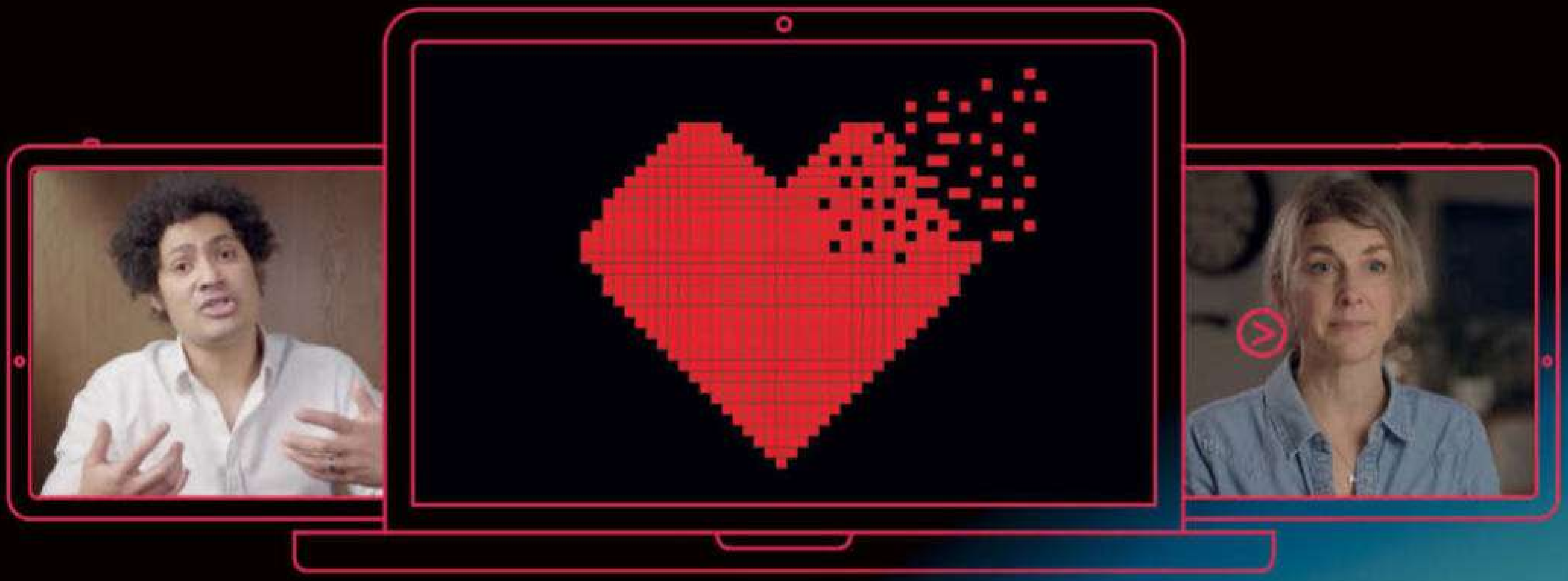

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Animal behaviour

Parent birds sing a song of mitochondrial manipulation

ZEBRA finches sing a special song to their eggs when the weather is hot, and this seems to program hatchling cells to create less heat.

Zebra finches, which mostly live in arid areas of Australia, sing "heat calls" at temperatures above 26°C. Previous studies have found that the calls seem to reduce the growth of offspring. A smaller body may help young birds cope better in higher temperatures.

Now, for the first time, we also have evidence that when zebra finch eggs are exposed to heat calls, it changes how mitochondria – energy-generating units inside cells – work in hatchlings.

Mitochondria convert food energy into a molecule called adenosine trisphosphate (ATP), which powers cells. They can also use food energy to generate heat.

To investigate, Mylene Mariette at Deakin University in Geelong, Australia, and her colleagues kept zebra finch eggs at 37°C for 10 days, before transferring them into one of two incubators.

In one incubator, the researchers played recordings of heat calls from 10am to 6pm every day until the eggs hatched. In the other, they played other zebra finch calls that aren't associated with heat.

At 13 days after hatching, the researchers collected blood samples from a total of 46 nestlings and measured mitochondrial activity. They found that mitochondria from birds exposed to prenatal heat calls produced more ATP relative to heat production compared with offspring that developed with control calls (*Proceedings of the Royal Society B*, doi.org/g8sf). **Carissa Wong**

Health

Cataracts may be linked to dementia

OLDER people who have cataract surgery are less likely to develop dementia afterwards.

The effect could be because people who lose their eyesight typically spend more time at home, and so get less mental stimulation – or it could be down to a strange effect that cataracts have on the colours that reach the retina at the back of the eye.

Cataracts, which involve the lens of the eye becoming cloudy with age, are one of the most common causes of vision loss in older people. They are fixed by replacing the lens with a plastic one.

Sight loss is a known risk factor for Alzheimer's disease and other forms of dementia. So Cecilia Lee at the University of Washington in Seattle wondered whether cataract surgery would have a correlation with dementia incidence.

She and her colleagues took advantage of an ongoing US study that began in the 1990s to identify risk factors for dementia. They looked at the records of about 3000 participants who were 65 or older and had either cataracts or glaucoma, another eye condition that is treated with surgery. This was used as a comparison.

Over the next eight years, those who had cataracts removed had, on average, 71 per cent of the risk of getting dementia as those who had untreated cataracts. No such differences showed up in people with glaucoma (*JAMA Internal Medicine*, doi.org/g8sq).

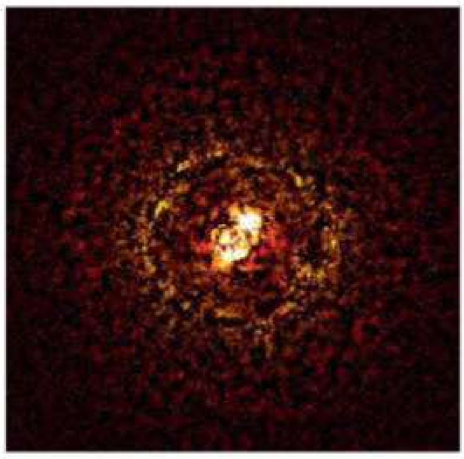
Cataract surgery could lower the risk of dementia by enabling "higher-quality sensory input to the retina and therefore improving stimuli to the brain", says Lee. Another idea is that as cataracts filter out blue light, this disrupts sensing by cells sensitive to blue light that help govern our body clock. Disturbing our circadian rhythm has been linked with dementia. **Clare Wilson**

Space

'Impossible' planet orbits binary stars

TWO stars with a combined mass at least six times that of our sun that are orbited by a gas giant make up the largest planet-hosting star system detected so far. The system may challenge our currents ideas of planetary formation.

Previous studies of planets in close orbit to high-mass stars have suggested that planets orbiting stars of more than three times the mass of the sun may be rare or even non-existent. This is because higher-mass stars emit larger amounts of radiation, which should cause the dense discs of material like gas and dust around such stars to evaporate before they can coalesce into planets.



ESO/JANSON ET AL.

However, Markus Janson at Stockholm University in Sweden wondered whether giant planets would still form around massive stars as long as they orbited at a great enough distance. Now, Janson and his team have found such a planet: a gas giant orbiting a young binary star system called b Centauri that is between six and 10 times the mass of our sun.

The researchers first directly imaged the system in March 2019 using the Very Large Telescope in Chile and then conducted follow-up observations in April 2021. They found that the planet, known as b Cen (AB)b, is 10.9 times the mass of Jupiter and orbits the two stars at 560 times the distance between Earth and the sun (*Nature*, doi.org/g8sj). **Chen Ly**

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Really brief

JAMIE GRILL/TETRA IMAGES/ALAMY

Tiny payments keep people exercising

A trial of incentives that encourage people to go to the gym has concluded that the best approach is to pay them. The most effective strategy in the US study was a points system that awarded people 22 cents that could be redeemed at Amazon for every workout (*Nature*, doi.org/gnqtj4).

Farmland becomes forest in 20 years

Tropical forests can rapidly re-establish themselves on farmland that has been abandoned because of low productivity. After two decades, these kind of sites in Africa and the Americas had regained 78 per cent of the attributes of old growth forest (*Science*, DOI: 10.1126/science.abh3629).

Vast eruption seen on a sun-like star

A huge cloud of plasma known as a coronal mass ejection (CME) has been seen blasting from a young sun-like star. The CME, the biggest spotted on this type of star and larger than any seen on our sun, might help us understand how similar events affected our solar system in the past (*Nature Astronomy*, DOI: 10.1038/s41550-021-01532-8).

Neuroscience

Falling asleep may boost creativity

WHERE does creativity come from? Some people, such as US inventor Thomas Edison, have said that inventiveness surges during an unusual state of mind just as we drift into sleep.

New support for this idea comes from a study that finds people gain insight into a maths problem if they enter the initial stages of sleep, then wake up. As people fall asleep, they may spend a few minutes in a state called hypnagogia or "N1".

Delphine Oudiette at the National Institute of Health and Medical Research in Paris tested the link between N1 sleep and creativity by getting people to tackle a maths problem. They were given number sequences and had to manipulate them by applying two rules to reach an answer. They weren't told that a simple shortcut would also give the right solution.

The team asked 103 people to carry out the maths task and then gave them a 20-minute break set up so they could nod off. The 16 per cent of participants who had cracked the shortcut before this stage of the study were excluded.

The researchers determined that 24 people had at least one 30-second episode of N1 sleep and promptly woke; another 14 passed through N1 into deeper sleep and the rest didn't fall asleep at all.

After the rest, these volunteers carried out the maths task a second time and 83 per cent of those who had only reached the N1 stage worked out the shortcut. The success rates for those who stayed awake or progressed to N2 sleep were 31 per cent and 14 per cent (*Science Advances*, doi.org/g8sr).
Clare Wilson

Ageing

P TOMLINS/ALAMY

Chemical in seeds of grapes extends lifespan of older mice

A SUBSTANCE found in grape seed prolongs the life of old mice by 9 per cent by removing worn out cells.

The finding strengthens the case for future anti-ageing therapies that target senescent cells – those that lose their ability to replicate and instead churn out substances that cause inflammation. These cells increase in number as we get older, and have been linked to various age-related conditions, including cardiovascular disease, type 2 diabetes and osteoporosis.

To find a substance that might destroy these cells, Qixia Xu at the University of Chinese Academy of Sciences in Shanghai and colleagues screened a library of chemicals. This turned up a substance in grape seeds called procyanidin C1 (PCC1).

At low concentrations, PCC1 seems to prevent senescent cells in a dish from producing inflammatory substances. At high concentrations, the chemical killed the cells, while leaving younger cells intact.

The team injected 171 mice that were 2 years old – equivalent to 70 in human years – with PCC1 or a control twice a week. On average, PCC1 increased the lifespan of mice by 9 per cent. The chemical also appears to improve the fitness of younger mice (*Nature Metabolism*, doi.org/gnp9vh). **Carissa Wong**

Zoology

Paler feathers linked to longer migrations

A STUDY of nearly all 10,000 or so bird species has found that the further they migrate, the paler their feathers tend to be. This is probably because it helps birds flying in sunlight to keep cool, says Kaspar Delhey at the Max Planck Institute for Ornithology in Seewiesen, Germany.

Delhey and his team used photos to rate the lightness of plumage, treating males and females as separate species because coloration is so often different between the sexes. They found short-distance migrants were significantly lighter than resident birds, and long-distance migrants were significantly lighter than short-distance migrants, even without controlling for factors such as body size or the conditions where the birds live (*Current Biology*, doi.org/g8sn).

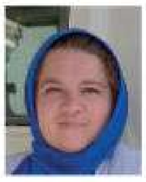
One implication is that migrating birds are going to find it harder to stay cool as the planet heats up. Rising temperatures may force darker species to fly only at night while migrating, says Delhey, or to fly higher during the day.

"These responses will probably entail costs, which may reduce individual survival, with potential negative consequences," he says.
Michael Le Page

MEDECINS SANS FRONTIERES
DOCTORS WITHOUT BORDERS

AFGHAN CRISIS APPEAL

'We're treating malnourished children and their number is increasing...'



MARIA FIX
MSF NURSE, AFGHANISTAN

"At the moment, we are the only major hospital in the region that is functioning. There are around 1.5 million people living in Helmand province and the health system across the region has essentially collapsed.

Our hospital is super-congested and we're incredibly busy. We have 300 beds, but at times recently we've had between 330 and 350 patients. That means a lot of juggling and making do, with children sharing beds. It's not ideal, but otherwise we wouldn't be able to treat all the patients coming to us.

Our paediatric department is overwhelmed. We're treating a lot of malnourished children and their number is increasing.

Even before the change of government, around half of the population relied for food support on aid organisations, but now a lot of that support has collapsed and many children are going hungry.

I don't think you ever get used to seeing malnourished children. Often they arrive dehydrated and in shock. We work to stabilise them in the emergency room before moving them to intensive care and then to the inpatient therapeutic feeding centre, where we feed them and slowly build up their strength.

It's very moving to see a child who has been so sick and malnourished recover and come back to life. But it's challenging at the same time, particularly when you know that, even if we stabilise them here and they recover, they're going to face the same problems – the same lack of food – as soon as we discharge them. But we do what we can and it's important that we do.

It's so important that MSF is here. When I was preparing to travel to Afghanistan at the end of August, people asked me why I was going there just as everybody else was leaving. When you're here, it does feel like Afghanistan has been abandoned – so many international organisations have left. But I'm so happy and proud that MSF has stayed. The people here are suffering and it's vital for us to be here, providing medical care to people who so desperately need it."

Right now, we are treating people wounded by war, malnourished children, and vulnerable pregnant women. In five locations across the country, our teams are treating emergency trauma cases and providing lifesaving medical care.

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The Afghan Crisis Appeal will fund MSF's work in Afghanistan as well as supporting our work in neighbouring countries.

Above: An MSF doctor checks on a premature baby in the neonatal unit of MSF's maternity hospital in Khost, 18 October 2021. *Photograph © Oriane Zerah*

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Vaccination push
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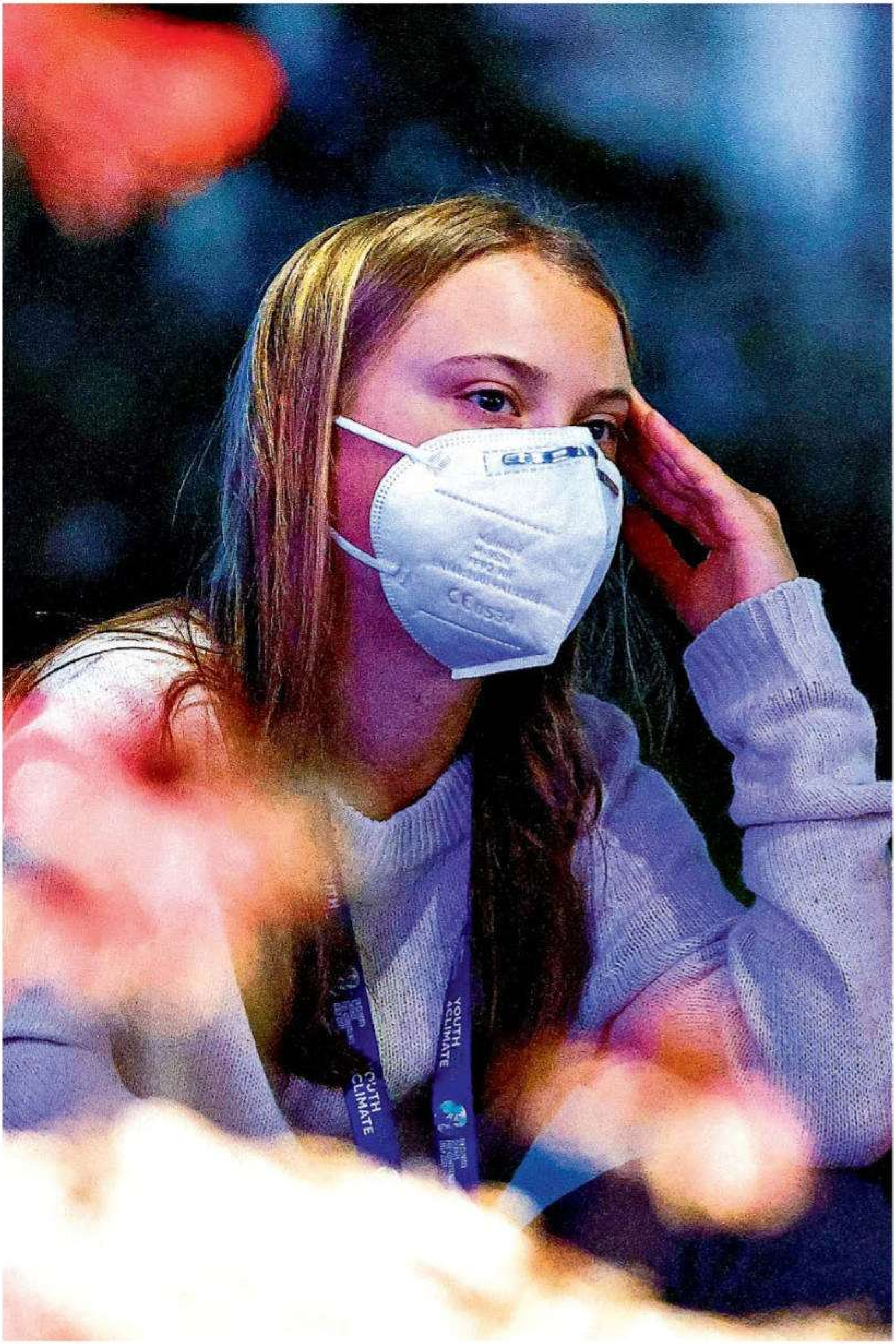
Protein structures
DeepMind's AI solved almost all human proteins **p23**

Billionaires in space
New era of space travel for those who can afford it **p24**

Missions to Mars
Piecing together new clues from our neighbour **p26**

COP26's impact
The Glasgow Climate Pact will shape the next decade **p29**



REUTERS/GUGLIELMO MANGIAPANE

2021: Review of the year

A year of tackling great challenges

Climate activist Greta Thunberg (pictured) derided world leaders in September for being all "blah blah blah" and no action, but November's Glasgow Climate Pact marked real progress on curbing emissions and adapting to warming.

This year also saw the first malaria vaccine and a leap forward in quantum computing. The covid-19 pandemic ground on, with uneven progress on vaccinating the world, while three different missions explored Mars.

▶ Coronavirus

Billions of covid-19 shots given in wealthy nations

By the end of 2021, several countries were on a third round of coronavirus vaccinations, reports **Clare Wilson**

REUTERS/ELOISA LOPEZ

A vaccination centre in a school in the Philippines in August

THE phenomenal covid-19 vaccine roll-out in 2021 demonstrates some of the best and worst aspects of modern medicine. It is now estimated that about 8 billion doses have been put into people's arms in the past 12 months – an incredible effort by health services around the world. But the vaccines haven't been distributed equally. While many people in high-income countries will have received three jabs by Christmas, only about 5 per cent of people in low-income countries were expected to have had at least one by the end of the year.

While the first few vaccines given outside a clinical trial happened in December 2020, it was in January 2021 that immunisation started taking off in the UK and other wealthy nations, with limited initial supplies meaning shots had to be prioritised for the most vulnerable.

Figures on the real-world effectiveness of the vaccines are encouraging. In the UK, two shots of the Oxford/AstraZeneca or Pfizer/BioNTech versions reduced infections by the delta variant by 67 and 80 per cent respectively, hospitalisations by 92 and 96 per cent, and deaths by 91 and 90 per cent. If vaccinated people do get infected, they are 63 per cent less likely to pass the virus on to others. We don't know yet how different these figures might be for the omicron variant.

There have been serious, but rare, side effects. In March, it became clear that the Oxford/AstraZeneca vaccine can cause a blood-clotting syndrome called vaccine-induced immune thrombotic thrombocytopenia, or VITT, which it turned out is also associated with the Johnson & Johnson vaccine, and is more likely in younger people.

In June, it emerged that the Moderna and Pfizer/BioNTech vaccines occasionally trigger a form of heart inflammation called myocarditis. This is more often seen in younger people, particularly males, although the incidence of myocarditis after covid-19 itself is six times greater.

The last few months of 2021 saw wealthy nations offering vaccine doses to under-16s, and in some countries, such as the US, to children as young as 5 years. Alongside this, a push for third or booster shots for vulnerable or older people and frontline healthcare workers has formed the cornerstone of Israel's efforts to tackle the delta variant and the UK's plans to get through a difficult winter and prepare for omicron.

Vaccines have also enabled countries that initially took tougher approaches to managing the pandemic to begin to reopen after lengthy lockdowns. New South Wales in Australia, for instance, kept its promise of easing restrictions, including in Sydney, once 70 per cent of people over 16 were fully vaccinated.

But the plan for wealthy countries to help low-income ones through a vaccine delivery coalition called COVAX has made slow progress, hindered partly by high-income nations buying so much stock for themselves and by an export ban in India that stopped expected supplies from a large manufacturer there. "We hit many problems," says Seth Berkley of the health body Gavi, one of the organisations leading COVAX.

Meanwhile, in high-income countries where supply is plentiful, a minority of people are still resisting vaccination, mainly due to mistaken beliefs about side effects. This helps drive circulation of the virus in the community, risking the lives of people who are vaccinated but still vulnerable due to age or ill health. ▮

Biotechnology

CRISPR-edited food goes on sale

Michael Le Page

COURTESY OF SANATECH SEED

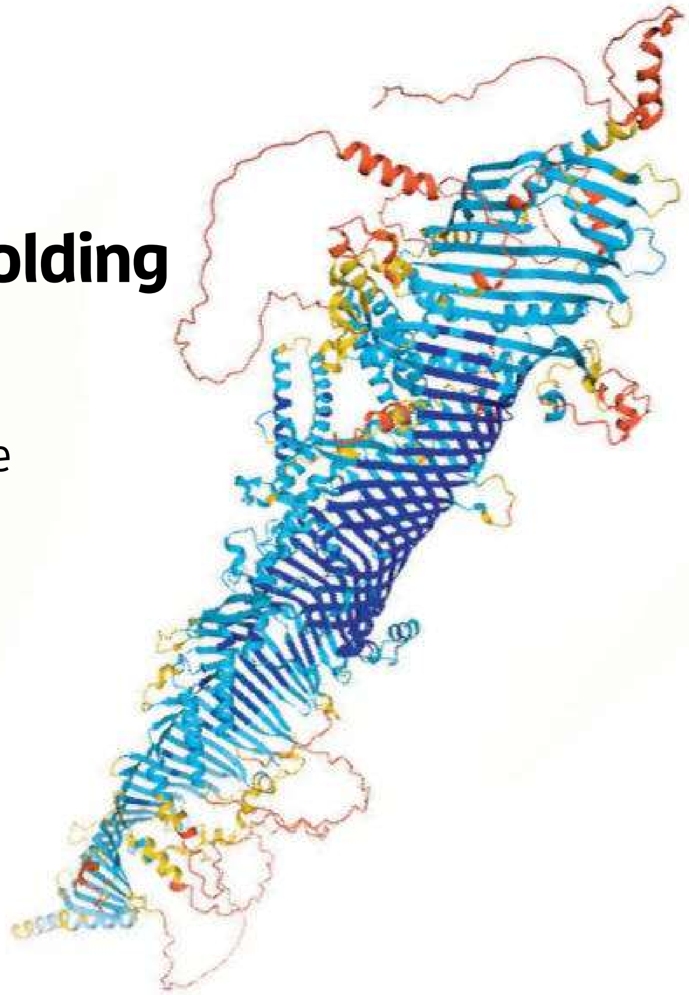
They may look ordinary, but in September these tomatoes became the first CRISPR-edited food to go on sale to the public. The tomatoes were developed by Hiroshi Ezura (pictured) at the University of Tsukuba in Japan. They are available only in Japan and have five times the normal amount of the nutrient GABA.

A lot more CRISPR foods could soon start to arrive on supermarket shelves in many countries. Next up could be a red sea bream edited to produce more flesh. Others in development include wheat that produces less of a carcinogenic substance when toasted, a lettuce that stays greener for longer and strawberries that are less likely to go mushy if damaged.

Interview

Investigating protein-folding becomes easier with AI

DeepMind released 3D models of the human proteome, and there is more to come, finds **Matthew Sparkes**



A 3D model of a fruit fly protein from DeepMind

IT TOOK decades for scientists to unlock the structure of just 17 per cent of the proteins in the human body. But UK-based AI company DeepMind raised the bar to 98.5 per cent in July when it announced that its AlphaFold model could quickly and reliably calculate the way proteins fold. This could lead to targeted drugs that bind to specific parts of molecules.

We caught up with Pushmeet Kohli at DeepMind to see how work is progressing with mapping almost every one of the more than 100 million known proteins that have been sequenced from across the tree of life.

Were you surprised at the success of AlphaFold, considering that figuring out protein folding previously required vast supercomputers?
We went in with the thesis that machine learning and AI had a role to play. But a lot of the team were uncertain as to whether this problem was solvable. It came as a very pleasant surprise.

You plan to release many more protein structures. Why not leave the problem with scientists who now have access to AlphaFold?
We open-sourced the model and the code so anyone on the planet can find the structure of any protein that they want. We're already seeing universities and labs across the world using our code. But the reason we're expanding the database release is because there's a lot of time and investment involved, and you don't want different people finding the structure of the same protein again and again, right? It will be very useful if we actually just do it once and for all, for everyone.

Which are you working on first?
We've received feedback from the community as to which organisms and which types of proteins we should prioritise next. So we're working along that road map, eventually moving into what we have committed to, which is releasing the structure of the entire protein universe.

Does that involve new work, or just applying AlphaFold at scale?
The team has been constantly improving the accuracy of the model. But we also want to expand what AlphaFold can do. So, we'd worked on single proteins, but complexes are important because when you look at the biological mechanisms at play, it's very infrequent that there will be a single protein just interacting with some other sort of small molecule in isolation. So, composite structures – that's what we have been expanding AlphaFold to do.

Will you ever reach a point where you have mapped everything, and AlphaFold can retire?
Proteins will change, life changes. As evolution operates, you will see different types of proteins coming into play. And so AlphaFold will have a life, not only in complexes, but also in thinking about how the structure is evolving.

And what about covid-19?
Very early on, we found the structure of all the SARS-CoV-2 proteins. Some had been experimentally validated, but many were very difficult to figure out by experimental methods. When scientists actually found the structures, it was interesting to see that ours were nicely consistent.

Now, with variants, again there is an element that these small mutations lead to changes in the structure, but AlphaFold is not currently sensitive to very small changes. So we want to make sure that future versions of AlphaFold are able to really be sensitive to mutations. ▮

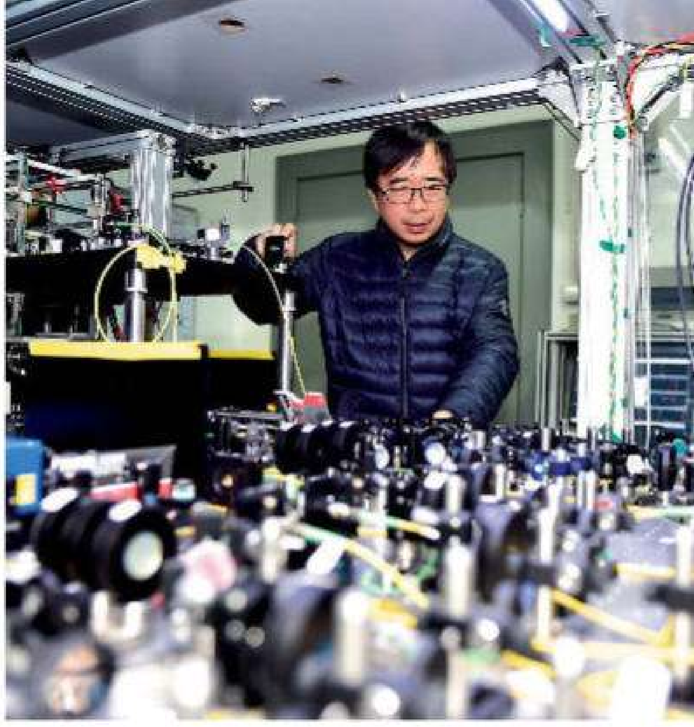
Profile
Pushmeet Kohli heads the Robust and Reliable AI and AI for Science teams at DeepMind

RIGHT: BEN PETER CATCHPOLE; TOP: DEEPMIND

Profile

The man leading China's quantum computing mission

The nation's world-beating quantum technology is largely credited to Jian-Wei Pan, reports **Matthew Sparkes**



XINHUA/ALAMY

GOVERNMENTS and companies around the world are racing to build a useful quantum computer, and the stakes are as high as the R&D budgets. Such a machine could crack encryption wide open, boost the power of artificial intelligence and help develop unique materials and drugs.

A big player in the field is China, which has a centralised and extremely well-funded government project hoovering up talent, all under the oversight of one man: Jian-Wei Pan.

The same words crop up repeatedly when you discuss Pan with those who know him: reserved, focused, driven and bright. He is often referred to as the "father of quantum".

He attended the University of Science and Technology of China (USTC) in 1987 and later the University of Vienna in Austria for his doctorate, ultimately returning to USTC to run one of the largest and most successful quantum research groups in the world. In Vienna, he worked under the prominent physicist Anton Zeilinger, who later said: "I can't imagine the emergence of quantum technology without Jian-Wei Pan."

Gregor Weihs at the University of Innsbruck, also in Austria, worked with Pan in Vienna and recalls his time there. "Initially he didn't have any experimental experience, but it was obvious that he understood quantum physics better than any of us, and had amazingly creative ideas," he says.

"He was certainly driven and motivated to build bigger things," says Thomas Jennewein at the University of Waterloo in Canada, who also worked with Pan in Vienna and helped him set up a new quantum research lab at USTC in 2002.

After returning to China, Pan had a meteoric rise. He was elected to the Chinese Academy of Sciences in 2011, its youngest ever member, and the World Academy of Sciences the following year. He became vice-president of USTC in 2014.

Pan's work has yielded huge results – it has been cited in nearly 50,000 other scientific papers – and has in turn led to a lot of government investment. A quantum laboratory that was opened at USTC in 2020 cost a reported $10 billion. Such backing has yielded big results of late.

Tech giants and research teams around the world have been in a race to outdo each other when it comes to quantum supremacy, the point at which a quantum computer can solve a problem that is impossible for classical computers. In July 2021, USTC announced it had surpassed Google's claimed quantum supremacy achievement by solving a problem three orders of magnitude harder than that performed by Google's Sycamore machine. In September, USTC bested its own benchmark by another three orders of magnitude.

Space travel

Space tourism is go – for the billionaires, anyway

THIS year, the extraordinarily wealthy flocked to space. After decades of deferred promises, the space tourism industry got going in earnest, beginning with short flights aboard privately funded craft.

Three different commercial ventures carried ultra-rich passengers into space in 2021. It began with Richard Branson, who took a 90-minute suborbital flight aboard his Virgin Galactic space plane, SpaceShipTwo, on 11 July. Whether or not the flight counts as having gone to space, though, remains a contentious subject – the US government defines space as beginning 50 miles (or just over 80 kilometres) up, which was the altitude of Branson's flight, but the internationally held definition of space, the Kármán line, is 100 kilometres above Earth.

Following the US government definition, Branson was the first

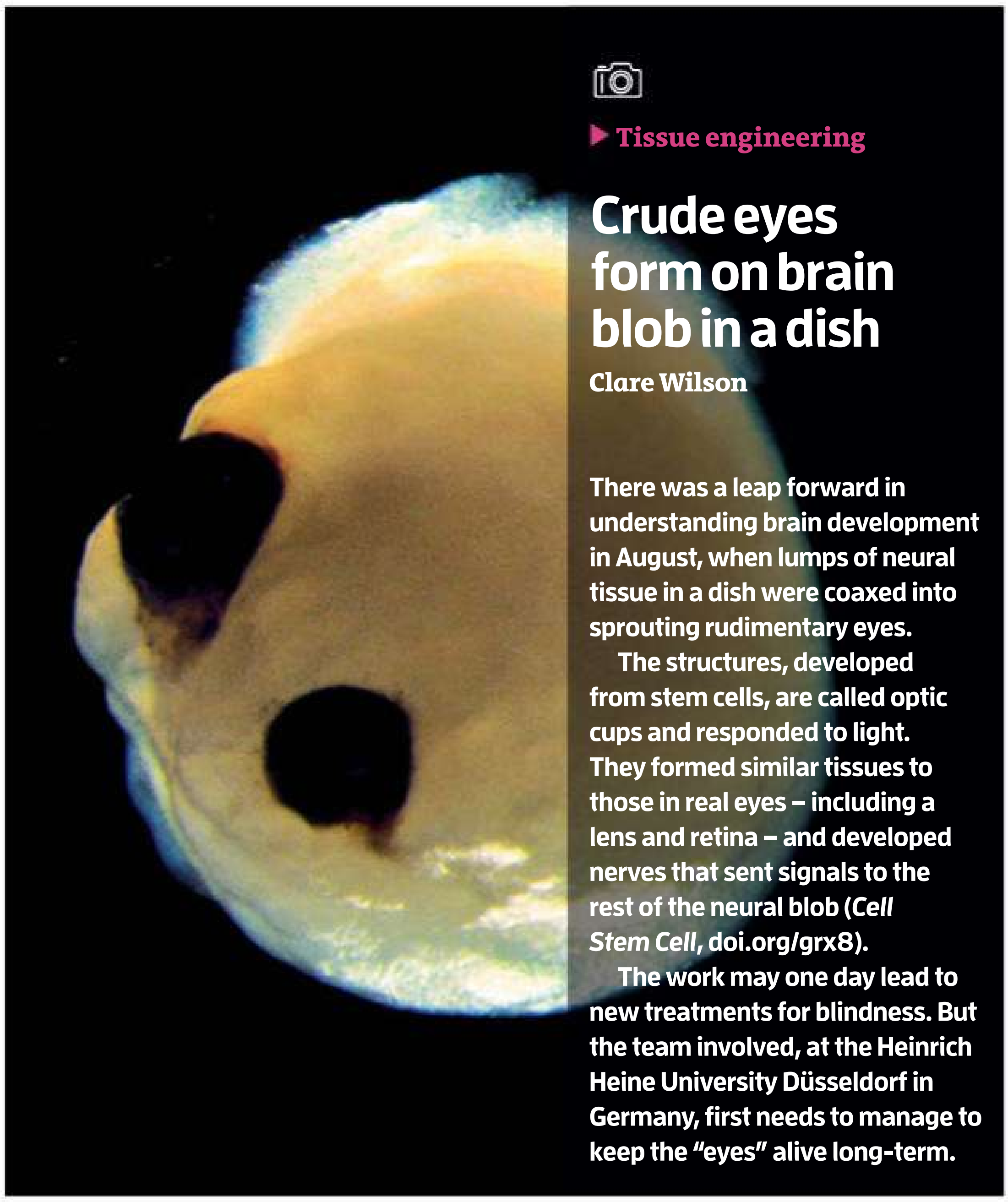
New Shepard's first crew and capsule (top); Virgin Galactic's craft and flyers

Jian-Wei Pan in a lab at China's University of Science and Technology

USTC is making great strides in quantum communication too. It recently revealed that the world's largest metropolitan quantum network – which involves banks, universities and government buildings across the city of Hefei in China – has been running for nearly three years. In 2016, USTC put the first quantum satellite into orbit, demonstrating unhackable communications with ground stations on Earth.

Pan's influence in Chinese science is large and growing. He is the vice-chair of the Jiusan Society, a minor political party that serves as a kind of think tank on scientific and educational issues.

It remains to be seen which country or company will be first to develop a practical quantum computer, but Pan and USTC seem likely to remain at the centre of this field for the near future. ▮



ELKE GABRIEL

▶ Tissue engineering

Crude eyes form on brain blob in a dish

Clare Wilson

There was a leap forward in understanding brain development in August, when lumps of neural tissue in a dish were coaxed into sprouting rudimentary eyes.

The structures, developed from stem cells, are called optic cups and responded to light. They formed similar tissues to those in real eyes – including a lens and retina – and developed nerves that sent signals to the rest of the neural blob (*Cell Stem Cell*, doi.org/grx8).

The work may one day lead to new treatments for blindness. But the team involved, at the Heinrich Heine University Düsseldorf in Germany, first needs to manage to keep the "eyes" alive long-term.

JOE RAEDLE/GETTY IMAGES; BLUE ORIGIN; PATRICK T. FALLON/AFP VIA GETTY IMAGES

person to visit space on a spacecraft made by his own company. Amazon founder Jeff Bezos came a close second on 20 July, when he rode his firm Blue Origin's New Shepard rocket on a suborbital flight past the Kármán line. While he reached a higher altitude than Branson at 107 km, the flight was shorter at 11 minutes, including 3 minutes of weightlessness. New Shepard flew again on 12 October with new passengers, including *Star Trek* actor William Shatner.

Meanwhile, in September, SpaceX pulled off the feat of sending a spacecraft into actual orbit without any government-trained astronauts aboard. Paid for and commanded by billionaire Jared Isaacman, this Crew Dragon flight, titled Inspiration4, was much longer than the other private flights, with the four passengers circling Earth for three days.

These trips show that norms in space flight are changing. They aren't the first examples of space tourism: non-government astronauts flew in the early 1980s and several wealthy thrill seekers have visited the International Space Station since then. However, the 2021 passengers are the first on private craft instead of rockets built by government agencies. If the pledges made by space flight firms are to be believed, there are many more of these flights to come.

> "These billionaire space tourists are the first to fly aboard private spacecraft"

While the per-person costs of most of these journeys weren't revealed, there is a reason that each of them has been bankrolled by a billionaire. As of August, Virgin Galactic was charging $450,000 per ticket for trips on SpaceShipTwo, and the going rate for a flight to orbit is around $50 million. But many in the industry expect competition to start bringing these costs down.

Still, the average person won't be able to afford to look down on our world from space in the next decade, but maybe mere millionaires will. ▮

Leah Crane

Space exploration

The month of Mars: Three missions to the Red Planet

February was an exceptionally busy month for our planetary neighbour, reports **Leah Crane**

OVER the course of just 10 days in February 2021, three missions arrived at Mars.

The first was the United Arab Emirates's Hope orbiter, which entered orbit on 9 February. Hope is the UAE's first interplanetary mission. While some of its systems couldn't be tested on Earth, the entry went smoothly.

"It was a once in a lifetime experience – a terrifying one, exhausting, but a very good one," says Omran Sharaf at the Mohammed Bin Rashid Space Centre in Dubai.

> "These missions are complementing each other, technically or scientifically"

The next day, China's Tianwen-1 mission joined Hope in orbit. Tianwen-1 is an ambitious mission, with an orbiter, lander and rover. After three months of testing instruments and making sure the landing site was free of obstacles, the orbiter released the lander and the Zhurong rover, which arrived at the surface on 14 May, making China the third country to land a rover on Mars.

"These missions are complementing each other, whether it's technically or scientifically, and they will all help us develop the next round of Mars missions," says Sharaf.

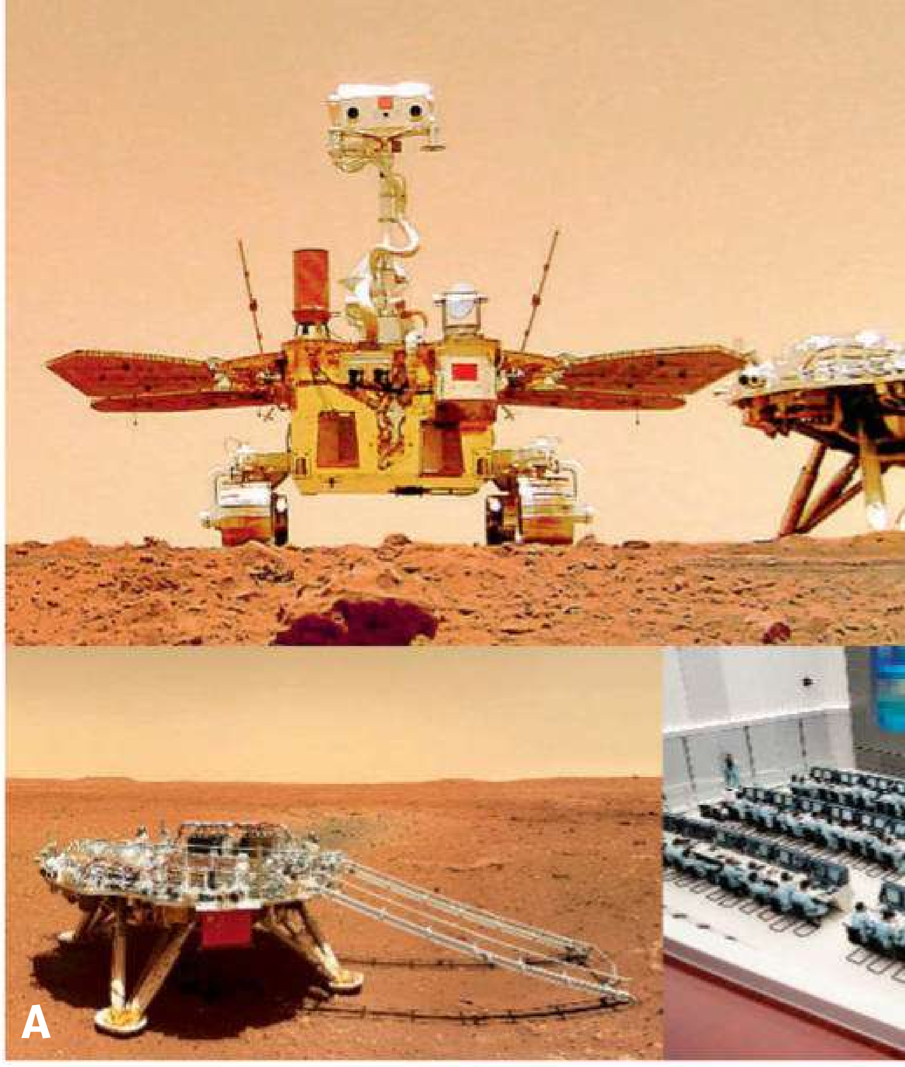
The third to arrive at Mars was NASA's Perseverance rover on 18 February. One of its goals is to collect and set aside samples to be returned to Earth by NASA's next mission to Mars. "Sample return has been a decade away for decades – it's still a decade away, but it's started," says NASA's Ken Farley.

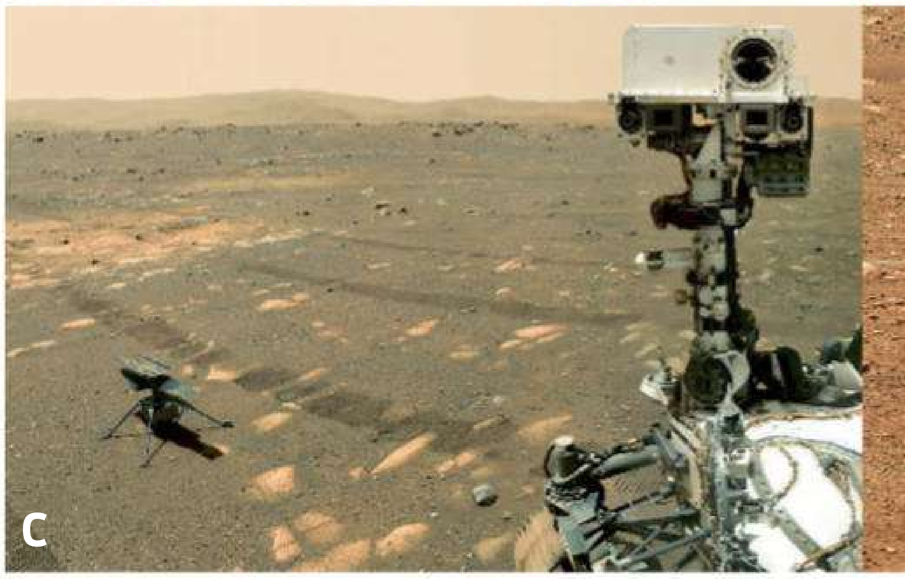
The Perseverance mission also carried the Ingenuity helicopter to Mars, the first drone to fly on another world (see interview, right). It has been remarkably successful – it was originally planned to make five test flights, but it had made 17 by early December, many of which were longer and more complicated than any of the planned tests. "We had orbiters and then landers and then rovers, and now it looks like we can fly as well," says Farley.

Perseverance has found volcanic rocks that appear to have been altered by contact with water, giving us insight into the ancient lake that used to cover its landing site. Zhurong has taken many images of the Martian terrain. Hope has imaged Mars's aurora and seen unexpected structures in the atmosphere.

"While the reasons are not laid down yet as to why we're seeing what we're seeing, it's very exciting," says Hessa Al Matroushi, the Hope mission's science lead.

"At the beginning there's always different puzzle pieces, and as you get more data they start to interlock," says Farley. With all these missions at Mars, the number of puzzle pieces will only increase, each bringing its own set of questions. But as the puzzle grows, our picture of the Red Planet will become clearer.



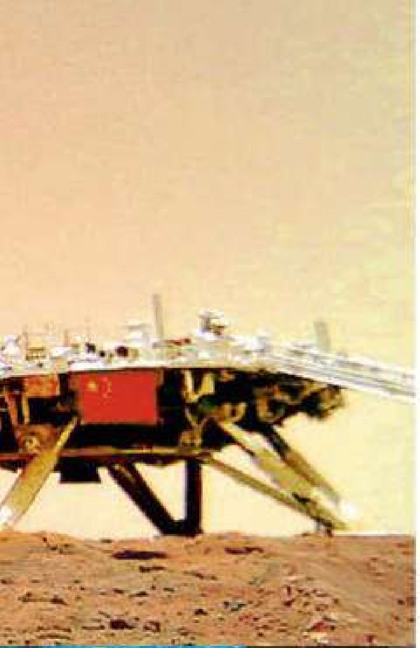


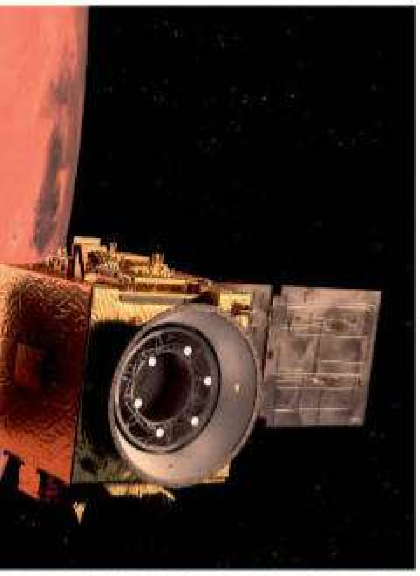
XINHUA/ALAMY; CAI YANG/XINHUA/ALAMY; EMIRATES MARS MISSION; MBRSC; NASA/JPL-CALTECH/MSSS; NASA/JPL-CALTECH

A: The Tianwen-1 mission. Clockwise from top: The Zhurong rover (left) taking a selfie; Beijing Aerospace Control Centre; Zhurong rover landing platform.

B: The Hope mission. The Hope orbiter launch; Illustration of the Hope orbiter.

C: The Perseverance mission. The Ingenuity helicopter and the Perseverance rover on Mars; Ingenuity.





Interview

"Nothing will ever top that moment when we announced the flight was successful"

After landing on Mars, Ingenuity became the first vehicle to attempt powered flight on another planet. *New Scientist* speaks to Theodore Tzanetos, the Ingenuity team's leader

OF ALL the craft that visited the Red Planet this year, perhaps the biggest leap forward was the Ingenuity helicopter. It was shuttled to Mars in NASA's Perseverance rover and took off on 19 April, making it the first vehicle ever to attempt powered flight on another planet.

The initial flight was a resounding success, as were the four that took place in the following fortnight. After those flights, the small craft was scheduled to end its mission as the rover drove away – but instead it continued to fly. By early December, it had made 17 ever more ambitious jaunts and scouted for Perseverance in the first part of the rover's mission to explore Mars's Jezero crater.

Theodore Tzanetos at NASA's Jet Propulsion Laboratory in California, the leader of the Ingenuity team, told *New Scientist* about the mission's extraordinary success.

What was that first flight like for you?

It was exhilarating, in one word. It's one of those moments in your life when you realise: "Wow, I can't believe this is really happening and I'm lucky enough to be in this room right now with these people." Nothing will ever top that moment when we announced the flight was successful.

I have to say, seeing the shadow of the craft as it took off for the first time was pretty breathtaking, even for someone not involved in the mission.

The shadows have kind of this mirror reflection effect. It makes it more real when you see your shadow, like when you see your reflection in the mirror. When you see the blades and the legs and the shadow is projected on the Martian surface, it really brings it home.

COURTESY NASA/JPL-CALTECH

Profile

Theodore Tzanetos is the leader of the Ingenuity team at NASA's Jet Propulsion Laboratory in California

What allowed Ingenuity to outlast its initial mission timeline?

Part of what we will look back on for years to come is that question. We designed it to last 30 sols, or Martian days – we couldn't afford any extra margin because the air is so thin that we couldn't carry any additional mass.

That made it difficult to design anything to last on Mars because Mars is very unforgiving – it's very cold, and the atmosphere is thin. But we're still running. Eventually, we'll be able to look back and learn what was the first component to fail, but for now we're just trying to use the craft as well as we can.

What has it accomplished so far?

Ingenuity is a technology demonstration. We don't have a science payload. Our mission was to prove that we can fly – that's it. We knocked out our first five flights and we were lucky that the helicopter was still functioning, and we were starting to see a glimmer of the functionality that we could have for a continuing mission.

We were no longer just a technology demonstrator. Then our mission became to continue pushing the limits and learn how to interact with this helicopter on a longer scale, and also to scout for Perseverance. That's been really rewarding, working with the rover team to figure out what would be the best areas to scout out. That's something I could have never imagined doing a year ago, when all we cared about was doing our first flight.

How do you think this concept will be carried forward in future missions now that we know it works?

We have a road map for that and it's called the Sojourner rover. It was a tech demo [that landed on Mars in 1997], this little rover the size of a microwave, and now we have Perseverance, which is the size of a car with all of these instruments on it. That's how I view Ingenuity.

"My dream is to see fleets of spacecraft in the sky on Mars, helping future human explorers"

We proved that we can fly, and now we have this ground truth to help us design the future of rotorcraft. My dream is to see fleets of spacecraft in the sky on Mars, potentially helping out future human explorers, but also performing their own science. ▮

Interview by Leah Crane

Pandemic

Remote working prompts a rethink of office jobs

Many people worked from home throughout 2021 and now we understand the pros and cons, says **Alice Klein**

EXPERIENCE INTERIORS/ISTOCK

Working from home has led to rises in productivity for some

THE covid-19 pandemic has forced millions of us to participate in one of the biggest social experiments of our time: what would happen if office workers largely abandoned their workplaces and began working from home? More than 18 months in, it is time to take stock.

One thing seems clear: more people working remotely has brought some benefits for the environment. With less commuter traffic, wildlife has been able to reclaim urban spaces while people have been tapping away at their home keyboards.

But what about the benefits to people? The major perks of home working include people having more flexibility to mould jobs around their family, exercise and leisure time, being able to wear whatever they like, controlling their own heating and lighting and not having to commute. The lack of commuting may be the biggest bonus, since surveys show that workers typically rate their commute as the worst part of their day, unless they walk or cycle.

Many people have also been able to get more done while working remotely, possibly due to fewer distractions. A survey by Boston Consulting Group of 1500 managers at large European companies found that more than half had seen productivity levels rise as their employees shifted to remote work during the pandemic.

"There used to be a lot of resistance to working from home because managers thought employees would just goof off and watch Netflix, but there's a lot more trust now," says Sue Williamson at the University of New South Wales in Canberra, Australia.

> "Surveys show that workers typically rate their commute as the worst part of their day"

However, the experiment hasn't been all positive. Many people forced to work from home have reported feeling isolated and finding it harder to switch off due to the blurred boundary between work and home life.

Many managers have also reported declines in innovation, which is probably because "it's hard to get those serendipitous conversations between people that spark ideas" when everyone is physically separated, says Anne Bardoel at Swinburne University of Technology in Melbourne, Australia.

Then there is "Zoom fatigue", the drained feeling that often accompanies virtual meetings, even though they tend to be shorter than in-person ones. This may be because people have a stronger sense of being on show while on screen and feel more pressure to present well, says Allison Gabriel at the University of Arizona.

As vaccines help to control covid-19, many organisations are hoping to reap the best of both worlds by letting employees work from home on some days and travel to the office on others. The coming months and years will undoubtedly involve trial and error as companies and employees settle on the optimum mix of office and work-from-home days. But one thing seems certain: now that office workers have been given a chance to really think about how they want their work lives to look, there is no turning back.

"It is this opportunity to reset and rethink how we actually work, and I think that's a very positive thing," says Bardoel. ▮

Medicine

World's first malaria vaccine

Clare Wilson

Decades in the making, October saw a malaria vaccine given the go-ahead for use outside trials for the first time, described as a "historic moment" by World Health Organization director-general Tedros Adhanom Ghebreyesus. Below, Jeywellan Ochieng receives the vaccine in Kenya on 7 October, the day the announcement was made.

This RTS,S vaccine reduces cases of severe malaria by only 30 per cent, but because the disease causes more than 400,000 deaths a year, it should save many lives.

Several other malaria vaccines are in the works, and some may be more than 70 per cent effective.

REUTERS/JAMES KEYI VIA ALAMY

REUTERS/PHIL NOBLE

COP26 president Alok Sharma was visibly emotional in the summit's closing moments

Environment

COP26 lays the groundwork for a decade of action

JUST days after it was agreed on by nearly 200 countries at the COP26 summit in November, the reverberations of the Glasgow Climate Pact were being felt.

In the immediate aftermath of the conference, the price of carbon in the European Union's carbon market hit a record high of €66 a tonne. Scotland's first minister Nicola Sturgeon came out against a new North Sea oil field, putting more pressure on the UK government to reconsider its approval. The European Commission set out a draft law to block imports of beef and other commodities if they are linked to deforestation.

Yet it will take a while for the Glasgow Climate Pact's eye-catching promise to "phase-down" coal to be fully adopted. For example, in October, China's coal output hit the highest level since March 2015.

It may take even longer for the effects of the pact's pledge to phase out "inefficient fossil fuel subsidies" to be felt, judging by the G7's slow progress on a past commitment to end them.

The achievements of the deal reached in Glasgow, UK, will play out over decades to come. Next year will be the first big test. By the end of 2022, countries are meant to deliver on COP26's "request" – diplomatic language that amounts to a commitment – to issue better 2030 emissions reduction plans.

> **"It will take a while for the Glasgow Climate Pact's promise to 'phase-down' coal to be fully adopted"**

Those plans must be aligned with the 2015 Paris Agreement's goals of holding global warming to 1.5°C above pre-industrial levels and well below 2°C. Current plans by Australia, Brazil and Indonesia are among those rated "highly insufficient" and in line with a 4°C future by independent analysts. Countries that have already set a stretching target, such as the UK's plan of a 68 per cent emissions cut by 2030, aren't expected to upgrade their ambitions.

India announced new goals at COP26, including sourcing half of its electricity from renewables by 2030, and will be expected to submit them in a formal plan to the UN. Officially, it should have done that by the end of 2020.

One issue that lower-income countries will watch closely in 2022 is whether higher-income nations are on track to deliver the $100 billion a year of climate finance they had promised by 2020 and that they expressed "deep regret" at missing. The figure is now expected to be hit in 2023, though US climate envoy John Kerry said in Glasgow that he thinks it may be met earlier.

COP26 resolved outstanding rules of the Paris Agreement on transparency, time frames for emissions targets and a new global carbon market, which will now take years to be established. Eyes will also turn to the formation of a new independent group, announced by UN secretary general António Guterres at the summit, to scrutinise net-zero pledges by the private sector. ▮

Adam Vaughan

REUTERS/FRED GREAVES

Clockwise from left: A firefighter in California in August; The aftermath of severe floods in Germany in July; East Flores in Indonesia after a cyclone and landslides in April; Unusually heavy snow in Madrid, Spain, in January

T-B: THOMAS LOHNES/GETTY IMAGES; ANTARA FOTO/ADITYA PRADANA PUTRA VIA REUTERS; REUTERS/SUSANA VERA

▶ Climate change

Extreme weather hits

2021's weather was striking for not just breaking records, but often smashing them, says **Adam Vaughan**

DEADLY fires, floods and freezes struck around the world this year, as a report by the world's top climate scientists said it is now an "established fact" that humanity's greenhouse gas emissions are linked to more-frequent, more-intense extreme weather.

"The sad fact is climate change and extreme weather have become the norm," says Christiana Figueres, former head of the UN Framework Convention on Climate Change.

Temperature records are usually exceeded by a fraction of a degree. Yet in late June, the village of Lytton in Canada broke the country's record high by almost 5°C, reaching 49.6°C. A day later, wildfires destroyed much of the community.

Other parts of the northern hemisphere were alight too. The largest blazes scorched the boreal forests in Siberia. And California, which has had several severe fire years in a row, saw the Dixie fire burn around 390,000 hectares, making it the state's biggest on record. Turkey and Greece were also badly affected. When looked at globally, wildfires released a record amount of carbon dioxide, the gas helping create the warmer, drier conditions for these events in the first place.

In July, Turkey endured a new temperature high, while Sicily in Italy saw Europe's warmest day on record a month later. South America was afflicted by drought, exemplified by the continent's second longest river, the Paraná, dropping to its lowest level in 77 years.

Too much heat wasn't the only problem. Texas shivered in a historic cold snap with temperatures as much as 28°C below average in February.

> "Climate change poses an existential threat to our lives, and the threat is here"

The freeze hit power and water supplies and hundreds of people died. One study found the event was made more likely by melting Arctic sea ice disrupting weather patterns.

Floods took a heavy toll too. The Chinese city of Zhengzhou in Henan province was deluged with more than 200 millimetres of rainfall in 1 hour on 20 July, an all-time national record. The resulting flooding of the city's subway system killed 14 people. The same month saw extreme rainfall devastate parts of Germany and Belgium, causing landslides and more than 200 deaths. South Sudan was wracked by its third year in a row of extreme floods.

In September, people drowned when basements in New York flooded as the remains of Hurricane Ida hit. "Climate change poses an existential threat to our lives, our economy, and the threat is here," said US president Joe Biden. ▮

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Following the increasing prevalence of the omicron variant of Sars-CoV-2, we have taken the decision to reschedule **New Scientist Live Manchester** to 12–14 March 2022. We think this will be a better time to welcome all our visitors, speakers and exhibitors in-person for a weekend that will be packed with thought-provoking talks, ground-breaking discoveries, interactive experiences and hands-on activities, workshops and performances. The final day of the show, Monday 14 March, will be dedicated to schools.

One thing that doesn't change with the change of dates: if you'd rather enjoy the event from the comfort of your home, all the weekend stage talks will be streamed live, while the feed from our new Engage Stage will also give home viewers a flavour of the wider event. We hope that this new date and hybrid format will give people wherever they are the chance to enjoy the stimulating experiences and engaging activities that New Scientist Live is famous for, in a safe and welcoming environment.

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A MIND-BLOWING
FESTIVAL OF IDEAS

Views

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Test your wits against *New Scientist*'s giant word puzzle p43

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Volcanic ash blankets the landscape in the Canary Islands p46

Columnists

Well, that was interesting

New Scientist's columnists see out 2021 by examining cryptocurrency absurdities, sci-fi botany, COP26's outcome and science's other corona

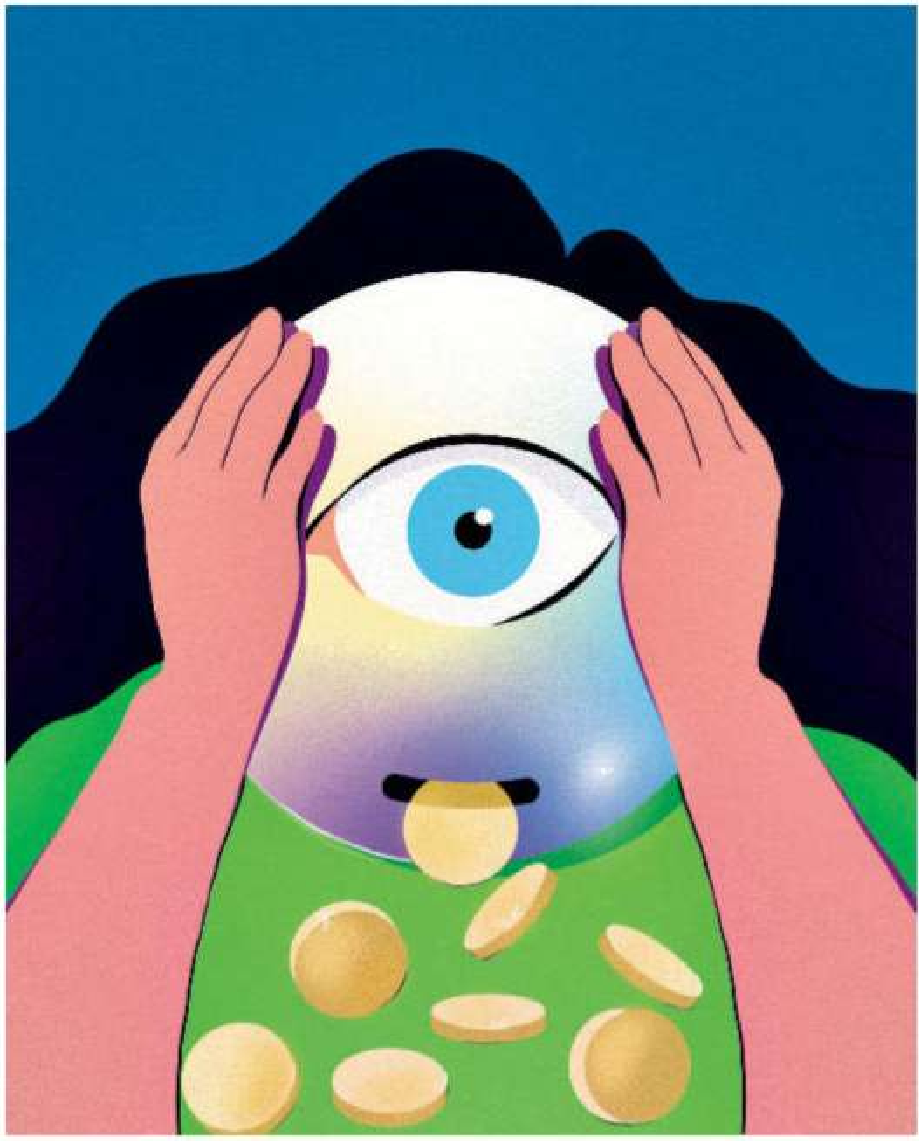
Annalee Newitz is a science journalist and author. Their website is techsploitation.com

IN THE waning days of this year, a meme has been making its way across Twitter that goes something like this: "If cryptocurrencies like Bitcoin were actually a reliable form of money, the porn industry would already be using them."

Pornography may not be your cup of tea, but adult content has, time and again, been a bellwether for tech upheavals. The industry spearheaded the VHS revolution of the 1980s and the web revolution of the early 2000s. Yet despite being known for its brash approach to everything, it has shied away from cryptocurrencies.

Maybe that is because they have become so absurd. Indeed, 2021 might be remembered as the year they finally went off the rails completely.

Take Worldcoin, which at first glance seems like a serious company. It is the brainchild of Sam Altman, an influential Silicon Valley investor, who raised more than $25 million for the firm's launch in October. The company admits that only 3 per cent of the world's population currently uses a cryptocurrency, but aims to change that. How? Well, this is where it gets odd. Worldcoin will give "as many people as possible a share of a new currency". Anyone who wants a Worldcoin can have one – as long as they are willing to look into "the Orb".



MICHELLE D'URBANO

That's right, Worldcoin's big technical advance is that it has created a shiny, silver ball about the size of a grapefruit called an Orb. You gaze into it, a camera inside takes a picture of your eyes and – poof! – now you have a Worldcoin in your app. Of course, the company also has a picture of your irises.

Like your fingerprint, each of your irises is a unique biometric attribute that can be used to identify you any time you look into a camera. On its website, Worldcoin has strange pictures of "Orb operators" asking people to gaze into shiny balls on a farm in Indonesia and on the streets of unnamed cities in Sudan and Kenya. The vibe is reminiscent of those edge-of-the seat moments in a horror film when something horrible is about to happen to the protagonist. You want to scream: "Don't look into the Orb!"

Meanwhile, there's more nonsensical crypto messaging from a company called Block. To catch you up, Block used to be called Square, a company that offers a beloved app that allows small businesses to do easy credit card transactions. Block is run by Jack Dorsey, who was the boss of Twitter before he abruptly quit in late November.

What new stuff is Block going to do? All we know is that it seems to be something to do with blockchain, which is the technology that makes cryptocurrencies work. We can also see that the company's executives are now represented on its website as photographs that have been plastered onto cubic blocks in such a way that their features look awkwardly distorted. They are literally blockheads – not the look I would choose if I were rebranding a company.

If you try to figure out more by going to the company's website at block.xyz, you will discover that Block's crypto venture is called TBD54566975. And TBD54566975 exists only as a Twitter account, whose description is simply the hashtag #Bitcoin with a few ocean wave emoji underneath.

Definitely not a joke, right? If you are feeling a little uneasy, just look into my Orb. Nothing could possibly go wrong. ▮

Graham Lawton is a staff writer at *New Scientist*. Follow him @GrahamLawton

AND so this is Christmas, and what have we done? A year ago, I was writing a preview of 2021, which was shaping up to be pivotal for our fractious relationship with the environment. The UN was getting ready to launch not one, but two decades: one on ecological restoration and one on ocean science for sustainable development. The world was preparing to get to work on a new set of biodiversity targets. And the headline act, of course, was the COP26 climate summit in Glasgow in November.

I spent a head-spinning week at COP26 and still have very mixed feelings about its outcome. There were genuine successes – not least an agreement to renegotiate targets on an annual rather than five-yearly basis – but also some glaring failures. The worst of these was the continuing and shameful failure by high-income countries to honour pledges to the poorest nations on compensation for the loss and damage they have incurred due to climate change. Indigenous people also continue to be marginalised and exploited even though their lands provide the world with priceless ecosystem services (which don't come for free, counter to the wisdom of the classical economics that has done so much to get us into this mess). They and their cultures are literally keeping the world liveable. We owe them the earth.

> **"I spent a head-spinning week at the COP26 summit and still have very mixed feelings about its outcome"**

This is an aspect of the climate change story that I was woefully ignorant of before Glasgow. Low-income countries bear the least responsibility for the climate crisis, but shoulder the greatest burden. Richer nations got that way through industries that pump greenhouse gases into the atmosphere while pillaging the poorer nations' natural resources. COP26's failure to rectify these historical injustices was, I fear, a historic mistake.

The parallels with covid-19 – which I also spent much of 2021 covering – are depressingly clear. Rich countries cornered vaccines and ignored the warnings of the World Health Organization that nobody is safe until everybody is safe. The threat of the omicron variant reveals the self-destructive folly of pandemic nationalism.

You could say the same about climate nationalism. There can be no global solution without global justice, but that is nowhere to be seen. Trust is already an issue that threatens the legitimacy of international efforts to curb climate change.

Experts say that the continued failure of Western governments to honour their promises also opens the door to legal action to force them to do so, or even to extract reparations. The 2015 Paris Agreement explicitly ruled this out, but it is an open question how much longer this red line can hold in the face of rising frustration and anger. I am now woke to those injustices. (I use "woke" advisedly and think progressives should reclaim it as a badge of honour.)

Looking forwards to 2022, the highlight ought to be the completion of the long-delayed new framework for biodiversity. The talks began last year and were due to resume next month, but have been postponed because of the difficulties posed by omicron. By this time next year, we may well have run out of Greek letters with which to name coronavirus variants and be bemoaning the failure of COP27. What have we done, indeed. ▮

James Wong is a botanist and science writer. Follow him @botanygeek

WHAT with everything that has happened this year, I have found myself at home watching the box more often than usual. That was especially true recently when I was laid up in bed for three weeks with covid-19. I spent my time largely watching my favourite genre of film: science fiction. This has made me realise how surprisingly often my main passion – plants – plays a vital role in the plot of such films. And so, as 2021 draws to an end, I offer you my essential analysis of the botanical accuracy of a selection of sci-fi films.

Sometimes, the science is OK. In 2015's *The Martian*, botanist-turned-astronaut Mark Watney survives being marooned on the Red Planet by growing his own

potatoes. Producing arguably more calories per square metre of growing space than any other conventional crop, potatoes are a logical choice. Trials have shown that the nutritional value of spuds means a person can survive eating little else for up to two years.

However, Watney starts his farming operation using tubers from a shrink-wrapped packet. Live, raw tubers are constantly respiring and so wouldn't survive shrink wrapping. And you will have zero chance of getting a harvest by planting cooked spuds. A small but catastrophic error.

In 2007's *Sunshine*, a team of astronauts journeys to the sun on a ship filled with a payload of nuclear weapons in the hope of reigniting the dying star. The ship has a fascinating "oxygen garden", which is designed to produce the life-giving gas for our heroic crew through photosynthesis.

Given the average adult uses about 550 litres of oxygen per day, the crew of eight would require at least 4400 litres on a daily basis. Plants produce oxygen as a by-product of photosynthesis, and it has been calculated that for every 22 litres of oxygen produced, plants gain 150 grams in dry weight. That's 30 kilograms of new plant matter a day to meet the crew's needs. Even with the fastest-growing species on Earth, say a tropical bamboo, that is a big ask. The oxygen garden, however, was populated by Tasmanian tree ferns, which grow at barely a couple of centimetres a year under normal conditions. In practical terms, this garden would need to be hundreds of times bigger than is depicted in the film and include totally different species.

Finally, let's look at the 2012 film *Prometheus*. It opens with a panoramic shot of an alien race of "engineers" giving life to a supposedly barren Earth billions of years ago by seeding DNA into a waterfall. The same shot then pans over rolling green, mossy landscapes. But wait, wasn't Earth supposed to be barren? It is as if plants don't count as life. It is enough to infuriate even the most mild-mannered botanist. ▮

Chanda Prescod-Weinstein is assistant professor of physics and astronomy at the University of New Hampshire

THROUGHOUT 2021, one of my mentors has had to remind me that this year wasn't a good time to judge whether I like my job. After all, in the middle of a pandemic, no professor likes their job. An overstatement, perhaps, but probably not by much.

Despite all of this, my experience with teaching this fall reminded me of one thing that first drew me to becoming an academic: a life of learning. This semester, I taught an introduction to stellar astrophysics. In the process, I learned not just about teaching, but also some physics. So, as we finish another orbit around the sun and enter the third year of the coronavirus pandemic, let's talk about a different kind of corona that I came to better understand this year: the solar corona and the problem it is giving scientists.

Our local star is extremely average, and that is good news. If you had a diagram of the universe's stars and their properties, the sun would be right in the middle. In other words, our sun is a good sample of the cosmic stellar population.

> **"Let's talk about a different kind of corona: the solar corona, and the problem it is giving us"**

This is great for science because the sun isn't an experiment we can tweak. All we can do is observe. It is our good fortune that what we can learn by watching the sun is probably broadly applicable to lots of other stars too.

To say that the sun is average doesn't mean it is boring or simple. The fact that it is more or less one gigantic nuclear fusion reactor is perhaps its most exciting feature. I have treasured talking to my students this year about how – through a combination of incredible heat and strange quantum effects – our sun transmutes hydrogen into helium, and in the process creates the photons that illuminate our planet.

In about 5 billion years, the sun will expand, transforming from the yellow star we know into a red giant possibly 100 times its current size, and burn some of that helium into carbon.

For now, though, we have a yellow star that has layers like an onion. Among these is the core, where the fusion happens. Then there is a convective zone where hot blobs of plasma move up and cold blobs sink.

Most interesting of all is the sun's atmosphere, particularly a part of it called the corona. This is made of strands of plasma millions of kilometres long that look like flames dancing in a circle around the sun.

And here's the thing: you would expect that the corona – being one of the outermost layers of the sun and so one of the furthest from the nuclear fusion in the core – would be relatively cool. Not so. The corona is 500 to 1000 times hotter than the sun's surface. We have no idea why this is the case. This conundrum, called the coronal heating problem, is a major, unresolved puzzle.

As we head into 2022, I am excited about the possibility that one of my students will become interested in solving this problem. Even if not, I am hoping that by the time I come to teach this course again, I will be telling students about a fantastic discovery that has been made quite recently: the solution to the coronal heating problem. ▮

Editor's pick

So many questions, so many points of view

20 November, p 36

From Will Kemp, Wagait Beach, Northern Territory, Australia

In "Why is the universe intelligible?", the idea that in the future the cosmos may be only intelligible by machines gave me a jolt of recognition.

As part of a research project, I am using automated content analysis software to analyse a large number of environmental reports. I feed it a "corpus" of text and it uses natural language processing and machine learning to analyse them and provide an output, supposedly to help me understand the content. The problem is trying to understand the software's output is almost as hard as reading the documents.

I have no doubt the software understands the data I have fed it, but it seems I am not capable of understanding its interpretation.

From Martin van Raay, Culemborg, the Netherlands

When you ask "Why do we exist?" and so on, this implies a reason, a goal, a purpose, so therefore a design and ultimately a designer. I would have been more comfortable with "How do we exist?", as this asks for the laws of nature that make things possible and that govern the way reality functions.

From John Woodgate, Rayleigh, Essex, UK

"Why is quantum theory so strange?" It isn't a final theory, even though it passes all current tests. It is a bit like Pythagoras's theorem, which also passes every test, but is just a glimpse of a universe of geometries.

If our species was so kind, where did it all go wrong?

27 November, p 38

From Bryn Glover, Kirkby Malzeard, North Yorkshire, UK

It would be difficult to deny that the whole of recorded human history has been one of extreme and excessive brutality between ourselves. The Romans were appalling and every so-called civilisation since has been guilty of similar obscenities; it is only in the past few decades that some sort of universal attitude of care and tolerance for other members of our species has become the norm rather than the exception.

If we are to accept the basic premise of Kate Ravilious's article, then we must also believe that caring, sharing *Homo sapiens* underwent some sort of radical change of attitude to become brutal, perhaps around the time that "civilisation" set in. If so, then maybe the acquisition of private property, accumulated wealth, organised religion and acceptance of social hierarchies could be considered as possible causes.

To save Earth, let's start mining in space

13 November, p 38

From Charles Joynson, Rayleigh, Essex, UK

You report that some of the metals essential for modern renewable technologies are obtained in very environmentally damaging ways.

An alternative is to get them from asteroids. In his book *Mining the Sky: Untold riches from the asteroids, comets and planets*, John Lewis says that a single asteroid can contain $20 trillion of iron, nickel, platinum and cobalt. This method would be less damaging to the environment if the power to build the rockets were supplied by renewables, and if the propellants were oxygen and hydrogen.

From William Hughes-Games, Waipara, New Zealand

To make the devices that are needed to save us from climate change, we need to have a completely circular economy. In addition, we must examine sources of minerals that don't have to be mined – for instance, tailings from old mines in which only the mineral that was targeted at the time was removed. There is also coal ash, some sources of which are rich in needed metals.

Lots of shipping could go over land instead

27 November, p 45

From Richard Oliver, Attenborough, Nottinghamshire, UK

The article "Swabbing the decks" highlighted the difficulty of even a 50 per cent decarbonisation of global shipping. Perhaps a few extra options could help.

One is to move global shipping onto railways and canals. Almost everyone lives on one of Earth's two biggest land masses, so there is no great need for sea crossings. Trains can be electrified and powered by renewables. More barges could also be used on rivers and canals, propelled by electric-powered tow-path tractors.

A few sea crossings would still be required. Nuclear power is a well-developed, low-carbon technology for sea propulsion. Nuclear-powered tugs could tow barge trains across straits and to islands before transferring goods onto connecting trains.

Explanation for maths anxiety doesn't add up

27 November, p 25

From Stephen Matthews, Melbourne, Victoria, Australia

I have to take issue with Michael Brooks's view that a general fear of mathematics felt by many people is rooted in the ancient Greeks putting the subject on a pedestal, making it somehow mystical.

As Brooks points out, maths is elite in that, by its nature, it excludes those who don't understand or "get it". However, the explanation of so-called "maths anxiety", apparently rife in the modern world according to Brooks, is nothing to do with ancient Greek attitudes. The root of it is that maths is difficult and has to be learned in exacting precision. Moreover, it has to be well taught with a clear view to its relevance to everyday life as well as to high-flown scientific concepts.

We use the word "discipline" to describe a field of knowledge, and it is discipline that is required in the teaching and learning of mathematics. The ancient Greeks understood this, and their foundations are as sound today as they were 2000 years ago.

From Graham White, London, UK

Brooks claims that "maths is endowed with an almost sacred status for the power of numbers", and that this ultimately leads to a great deal of maths anxiety.

I have always been really terrible with numbers. Early on, it looked as though this would harm any sort of academic career. This changed when I got to secondary school and I started geometry: I found it easy and satisfying, and I now have maths degrees from the University of Oxford and the Massachusetts Institute of Technology. I still can't add up very well.

One step forwards, two steps backwards

6 November, p 13

From Lucy Roberts, Wantage, Oxfordshire, UK

You report that it is possible to use around 7 per cent less energy on regular computing tasks in the UK by careful scheduling. Next to this story is an article on the imminent arrival of energy-intensive space tourism. Is this juxtaposition an expression of the editor's despair? It certainly reflects mine. ▮

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By the Pricking of My Robotic Thumbs

A pianist faces a difficult choice when it comes to playing a new piece, in this short story by **Mary Robinette Kowal**

The low November light swept in under the clouds and flooded the wall of windows with golden light. Inez Townsend tilted her head away from the glittering sea water outside the Harpa concert hall and hoped that the reporters thought she looked interested, not squinty. She had agonized over what to wear to her first press conference and finally settled on standard concert attire, a simple black tunic, but had given a nod to her new home in Iceland by swapping a pair of knee-high black boots and leggings for her usual pumps.

The audience was a mix of high-level donors and journalists. It was easy to tell them apart, and not just because the journalists had lens augments glinting from their foreheads like third eyes, but the donors sipped champagne and wore natural fibers that made all the printed fabrics seem stiff and flat. Thank God her dress was cotton.

Next to her, Sóldís Vilhjálmsdottir was effortlessly glamorous, with her silver curls tumbling around her face as if she'd just woken up from a tryst with Odin. The Chief Conductor and Artistic Director for the Icelandic Symphony Orchestra was tall and slender and had lines that made her face seem more interesting with every one of her seventy-six years. Just sitting next to her made Inez feel like her life was finally taking off.

All she had to do now was not remind anyone that she was all of twenty-two and the least experienced person in the room.

"Here, yes, we are happy to introduce to you the results of our competition for emerging voices." Her voice had the breathy Icelandic aspiration at the ends of each word as if the wind were snatching extra sound from between her teeth. "First, please meet our new composer in residence, Ragnhildur Leifsdottir. Ragnhildur is an Icelandic composer, of course, who had studied at the Royal College of Music in London before returning here. She has already had success in Europe with her work, Autumn Concerto. Tell them what you have written for us.'"

On her far side, Ragnhildur blushed and studied her hands, twiddling her thumb augments with obvious nerves. Her blond hair was pulled back in a bun so severe that the little tendril in the front looked like a comma. "It's an orchestral piece with solo piano–"

> **"It is structured in three movements, and it is for orchestra and solo piano with twelve fingers"**

Sóldís moved the microphone closer to Ragnhildur and Inez made a note to speak up when it was her turn.

Clearing her throat, Ragnhildur started again. "It is called Einhverfjöll, which for those of you without augments, translates to 'Some Mountains.' It is structured in three movements, Svartur or 'Black,' Blár or 'Blue' and Ljós or 'Light,' and it is for orchestra and solo piano with twelve fingers."

Inez twitched, almost bodily turning to stare at Ragnhildur. Twelve fingers. That meant augments. Inez didn't have augments. Augments were the unholy in the sight of God– No. No, she knew lots of good people with augments and–

Sóldís turned to look at her. With effort Inez kept her smile fixed and was grateful that the conductor had been turned away when Ragnhildur had said twelve fingers. But seriously. To just announce that without asking her?

"Now, please allow me to introduce our pianist, Inez Townsend, an American pianist here on scholarship to the Iceland Academy of the Arts. Inez has been a finalist in the Van Cliburn competition, and she's been playing professionally since the age of thirteen. We especially picked her from a field of many other pianists because her approach to the piano seemed to pair naturally with Ragnhildur's vision."

Except for the part about twelve fingers. Inez's smile felt frozen to rigidity as Sóldís turned the microphone to her. "Thank you so much. I'm excited to be here." They could talk about it later. Questioning her conductor in front of donors and the journalists wouldn't win her any friends. "Ragnhildur's other work is stunning and I'm honored to be invited to play this debut."

The rest of the news conference passed in a blur of smiles and questions. The clouds scudded past Mt Esja, dimming the sun on the water to a bearable level, but an ache started to form between her eyes. Twelve fingers.

"Thank you all for your questions. We look forward to showing you our work in the spring." Sóldís pushed back from the table, standing with a smile. She lowered her voice

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Bio

Mary Robinette Kowal

Hugo and Nebula-award winning author Mary Robinette Kowal's books include *The Calculating Stars*, which is part of the Lady Astronaut series, and *Shades of Milk and Honey*

and beckoned Ragnhildur and Inez to follow her. "Now, we have champagne and I introduce you to people."

Inez's phone buzzed on her wrist. She looked down, keenly aware in this moment that if she were a normal person, she'd have a jewelphone in her ear. A jewelphone wasn't a real augment and yet she'd never been able to bring herself to have that fight with her parents.

Which was who was calling. She tapped it off, knowing what they were going to say.

"Something?" Sóldís stood next to her, with her head tilted to the side as she peered through her grey curls.

"Hm? No. No." But maybe she could get them to make a change. "Actually… well. Yes. The twelve fingers. That… that was a surprise."

"For me as well. But it is exciting, yes?"

"Well. But… I mean, is it really necessary? To have twelve fingers, I mean."

Sóldís steered her a little away from the table where they'd been for the press conference, leading her to face the windows so that their backs were to the room. "Is it a problem?"

Yes, of course it was a problem. Inez didn't even have pierced ears, much less any sort of augmentation. But her heart started to push against her ribs and the large room seemed to tighten around her.

Leaning down, Sóldís's lips were pursed as she studied Inez. "You ask if it is necessary. Surely you are not suggesting that we suppress Ragnhildur's vision."

"No. No, of course not." She swallowed and sweat beaded at the back of her neck under her hair. "I was just surprised. It's… it's not something that I'm entirely comfortable with."

"I can see this troubles you." Straightening, Sóldís faced the water, fingers steepled in front of her as if she were contemplating a score. "Here is my thinking… If you feel strongly that this is something you do not wish to do, we will not, of course, force you. You can return the money and we can award it to one of the runners-up."

"Oh. I didn't mean… I just wish that someone had asked."

"Yes. Of course… Of course, I also wish that you had mentioned in your interviews that you had some parameters under which you would not work."

"I didn't say that." The pain between her eyes crept around to her temple. She couldn't afford to return the money. And even if she could, the grant came with a visa and she needed that. She needed this whole thing as a stepping stone to get citizenship in Iceland. She swallowed and tried again. "The fact is that I don't have robotic thumbs and I… I can't afford them. Not anything that you could play a concert with."

Beaming, Sóldís spread her hands. "Is that the only obstacle? But of course, we will provide them. We have a sponsor and you will have the very best quality thumbs."

"Great." Inez's smile probably looked as ill as the sweat slicking her back. "That solves everything."

Except her family.

#

Inez was crouching in front of her apartment's tiny refrigerator with a bag of groceries on the floor when her phone rang. Her parents. Sighing, she tucked the skyr into an empty spot next to the ab-mjólk. There was only so long she could avoid her folks.

She transfered the call to the kitchen's wall screen. "Hi, Mom and Dad."

"Hi pumpkin!" Her father's cheery voice made her shoulders relax. "What are you doing down there?"

"Putting away groceries." She slid the frozen plokkfiskur into the even tinier freezer cubby.

"Show me your hands." Her mother's voice sounded crisp and monied and was complete artifice. It was the "I'm very angry voice."

"Seriously?" Inez swiveled on her heels, peering up at the screen her parents were on. She lifted her hands and waved at them. Ten fingers total and only two of them were thumbs. "Happy?"

"Yes, of course it was a problem. Inez didn't even have pierced ears, much less any sort of augmentation"

"No. I am not happy." Her mother shook her head. "I told your grandmother to watch that news conference. The only thing saving us is that she was at bingo this morning. Twelve fingers! Do you have any idea what that would have done to her?"

"Sarah…" Her dad put his hand on her mom's and leaned toward the camera. "We're just confused. Twelve fingers… Is that like four hands. A second pianist plays with you or… What does that mean, exactly?"

She stood up, dragging the bag of groceries with her. She wasn't going to look up like a child to have this conversation with them. "Solo piano. The piece requires thumb augments."

He sighed. "I'm disappointed to hear that."

Inez winced and put the bag on the counter. "It's not like it's a permanent augment. It's just temporary."

True and also, to really hit professional performance levels, she was going to have to wear them 24/7. They would have to become completely natural to her. She pulled the granola out of the › bag and set it on the counter.

Next to the thumbs. The box was out of the line of sight of the wall unit, but she still pushed it farther back so her parents couldn't see it.

"Sweetheart, you know that isn't the problem."

Inez shook her head and opened the cabinet to put away the small jar of peanut butter she'd found at the health food store. No one in this country willingly ate the stuff and it was outrageously expensive, but it reminded her of home. "How different is this, really, from wearing glasses?"

Not that she'd put the thumbs on yet. She'd had them for two days and they just hung out on her counter.

"It's not the same at all." Her mother leaned forward. "Augments rewrite your brain."

"Really?" She paused with a box of pasta in one hand and stared at the camera. "Now you're using science to make your arguments."

Her father was an engineer so that wasn't entirely fair and his sigh said as much. "Everything rewrites the brain. That plasticity is what makes it good at learning. You've spent your entire life learning to play the piano and neither your mother nor I could do more than Chopsticks. And that's because your brain has been rewired to pla–" His image froze with his mouth half open as the internet blipped. "–can't play without them."

"You froze for a moment."

He grimaced. "Sorry. We've been having brownouts all day."

"It's the electric cars." Her mother shook her head. "They keep promising to upgrade the infrastructure in our neighborhood, but..."

"But everyone gets home from work and they all plug their cars in at the same time." Her dad shrugged. "Progress."

"I get it. But I've also read that your brain flips back to normal after about two weeks of not using an augment."

"Really." Her mother looked dubious. "That's not what I've seen."

"I wasn't aware of your vast experience with augmented people."

"When people join the church, they stop using augments. So yes, I do have experience with augmented people and their transition back to their natural gifts." Her voice had gone icy, which meant that they were one sentence away from "don't get snippy with me, young lady." "There is nothing that–"

She froze mid-sentence, mouth twisted to the side and one eye half closed. Inez kept putting groceries away, waiting for her parents to start moving again.

The brownouts reminded her that this fellowship wasn't just about the music. Iceland, with its geothermal power, never had brownouts. It had beautiful clean air and a universal living wage and socialized medicine and all the things that her home might have had but chose not to. Well, maybe not the geothermal. But windfarms could have been a thing. This wasn't just about her career. If she could get citizenship in Iceland then she could serve as an anchor to bring her parents over.

The screen went dark. Call lost.

She sighed and tucked the shopping bag back into its elastic pocket to make a tidy ball for the next shopping trip. Sighing again, she grabbed the box from the counter and went into her living room where the piano was. Two pages of Einhverfjöll were sitting on the piano. Ragnhildur was still writing the rest, but Sóldís had slipped her these two pages as a sort of temptation or promise.

> **"Inside lay two robotic thumbs chased in silver and deep blue-green like the sun glinting on the Atlantic"**

Even on the page, even as a sketch, it was already beautiful. It should be something that filled her with delight, but she felt trapped into playing it. They should have asked her. Biting her lower lip, Inez pushed the piano bench back with her foot and sat down. The first notes dropped down like scattered rain on stone, clear and beautiful and not quite random. Then from the left hand a gust of wind pushed up into–

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She didn't have enough fingers.

The missing notes left aching holes in the music. Fine. Fine. She grabbed the box and broke the seal on the edges. Inside, in beautiful pristine white board, lay two robotic thumbs chased in silver and deep blue-green like the sun glinting on the Atlantic. A pair of transmitters lay next to them in a flat, discreet black with a geckoskin adhesive on the surface. Those would go on her ankles.

She knew that much from having seen colleagues use them in college to extend their reach. Wetting her lips, she pulled out the instruction manual and started skimming it. There were details and there was the quick start.

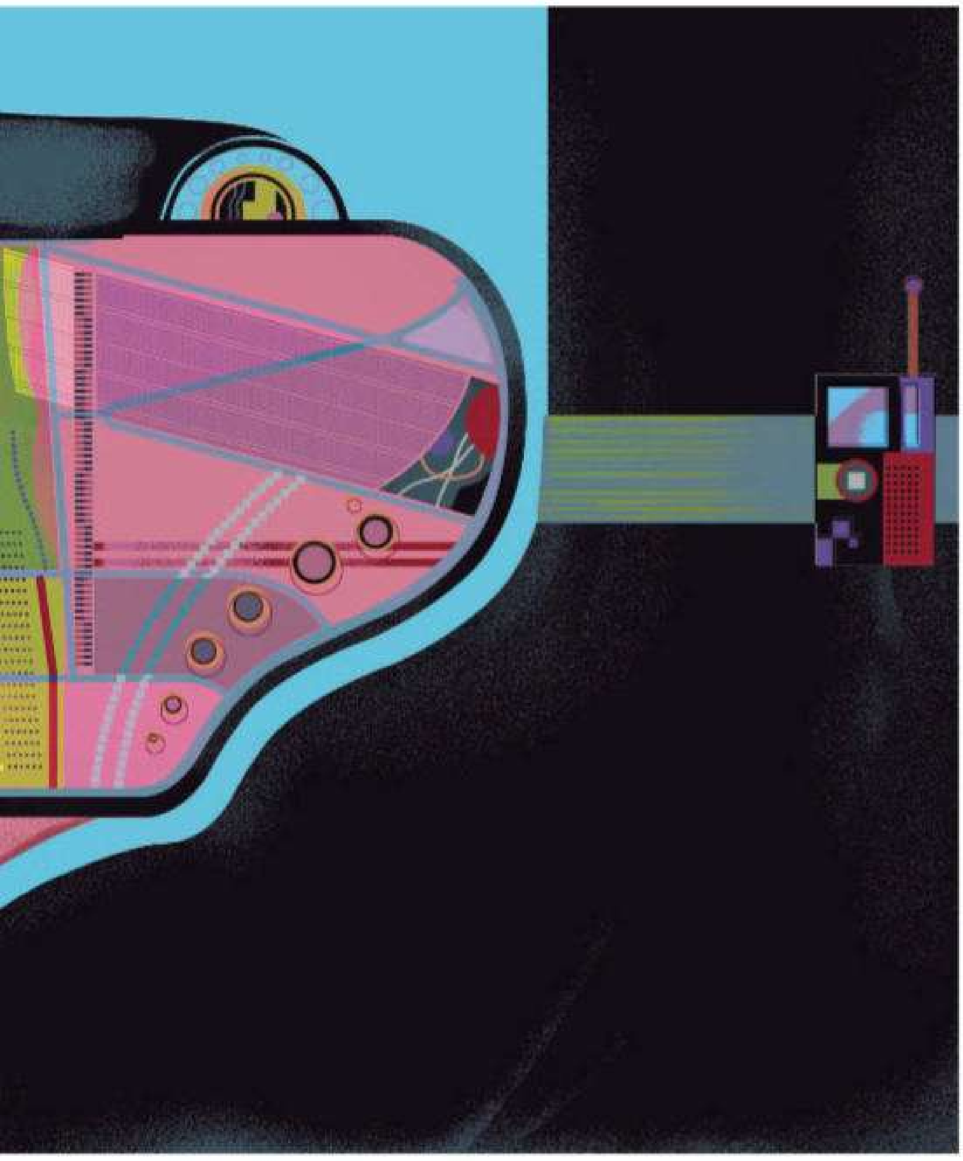
For now, that would do.

Inez tugged her woolen socks down and grabbed the left ankle sensor. She placed the flat sensor on the inside of her ankle, over the bone, where it would get signals sent to her big toe. The geckoskin adjusted and hugged against her ankle like the second skin it was designed to be. The other sensor went to the matching spot on her right ankle. Both felt like manacles and she had to resist the urge to kick them off. She'd get used to the sensation.

The thumbs went on with a similar patch, but also included a structural band that went around her wrist as a safety. The deep blue was a shocking contrast to her hand. Would it be better if it matched her skin tone?

Did the obvious artifice make it more offensive or less.

She wasn't sure and she wasn't sure that it actually mattered. She had to learn to use them, regardless of how she felt. She



touched the tips of the thumbs together and activated them.

They twitched and then waited, inert, next to the rest of her fingers. According to the quick start, she just had to move her big toe and they would respond accordingly. Concentrating, Inez tried to flex her toe. The right thumb moved.

The gorge rose in the back of her throat. Her chest tightened.

This was fine. She let out her breath. This wasn't any different from eyeglasses or a pacemaker, all of which were totally normal things. This was just a small, temporary augment.

Carefully, she touched the thumb to each fingertip on her right hand and then tried the same on her left. It was slow and awkward, but she managed it. Theoretically, the AI on board would calibrate as she went about her day, learning what ordinary movements were from her.

She looked back at the sheet music and set her hands on the piano. The geckoskin squeezed as she rested the thumbs against the specific keys giving her haptic feedback of the contact. Wetting her lips, she tried to play a scale with this new extra spread.

Her notes were slow and clumsy as if she were four again. Under her twelve fingers, the piano had become a strange landscape. The notes on the page of Einhverfjöll seemed even farther out of reach. Before she'd just been missing a few notes. Now she couldn't play at all.

The phone rang. Her parents again.

Inez ground her teeth together and ignored the phone. She started playing a scale. Twelve fingers. One at a time.

#

The cafe in Harpa was bright and cozy, even on dark days. As the calendar tipped into December, only about five hours of daylight remained and Inez tried to make certain she got daylight for at least some of them. The Christmas tree was up on the plaza outside Harpa and the lights reflected on the angled panes of the large windows. She stared past it toward the city, holding her cup of cocoa with her augmented thumb and palm while she stirred it idly with her natural thumb and index finger.

"Hallo!" Ragnhildur stopped on the broad stairs by the cafe table and held up a steaming cup. "I see we have the same idea."

"Windowless studios are good for concentration but… I was getting a little fuzzy-headed." Inez pushed back from the table and accidentally flexed her toe.

The mug dropped from her grasp, hitting the edge of the table and shattering. Cocoa went everywhere. She gasped as the hot liquid soaked her skirt. Her hands were clumsy as she tried to pull the cloth away from her skin.

Ragnhildur had danced back to avoid getting splashed and now darted forward, grabbing a napkin from the table. "Here! Can I help? Are you hurt?"

"Fine." She held the fabric away from her legs and dabbed at it with the napkin, which soaked through immediately. "Fine. It wasn't that hot."

Her cheeks were probably hotter than the coffee at this point.

"We all drop things." But Ragnhildur's gaze had drifted to the thumbs.

"Yes, but this was so stupid." Inez wanted to reassure her that this was an aberration. "All I had to do was keep my toe curled when I stood. It didn't even need to be tightly curled, just not flexed."

"I know." She held up her hand, which had thumb augments that moved as naturally as if they were a part of her body. "If… I might be able to rework the piece. I know you weren't comfor–"

"No." She let the sodden cloth drop and straightened. "Don't. I'll be ready when you finish writing it."

#

The main concert hall in Harpa was vast and lined with blood-red panels. The windows at the top of the seaward wall were dark oblongs of night. Inez shifted from one foot to the other while the orchestra tuned on stage. It was a familiar space. The murmur of the audience could have been in any language and still woven the same spell of anticipation.

Sóldís stopped beside her, resplendent in her white tie and tails. Her mop of silver curls was brushed back from her face in a smooth coif that would shake free with her energy over the course of the evening. "You must introduce me to your parents after. I did not see them during the pre-show reception."

"Her notes were slow and clumsy. Under her twelve fingers, the piano had become a strange landscape"

"They aren't here." She stared straight ahead at the bright stage.

Beside her, she could feel Sóldís turn to regard her, probably with an eyebrow raised. "Please tell me that we did not neglect to tell you of our arrangement with Icelandair."

"No. We're… No, they just decided not to come." It was just as well. She would have felt them judging her all night and the week beforehand. And on all the phone calls that she had stopped taking.

"Hm." She faced front again. "Are you ready?"

"Yes."

With a nod, Sóldís Vilhjálmsdottir strode onto the stage and her orchestra rose. The audience applauded their respects as she walked to center stage and bowed. Then she turned and held out her hand to the wings.

To Inez.

Head high, Inez walked the distance to her piano. The audience clapped, but not with the warmth of the welcome they gave to Sóldís. It was generous and appropriate and nothing more than that. They didn't know her.

Nodding to Sóldís, Inez sat at

›

her piano and looked past the ebony wood into the darkness of the concert hall. The glow from the stage just picked out the front row. Ragnhildur sat, with her elbows on her knees, leaning toward the light of the stage. It was her music they played tonight, but she wasn't up here. She had to trust Sóldís and the orchestra and Inez.

That… that was who she was playing for tonight.

Inez poised her hands over the keyboard, thumbs of her left hand spread to play that first gust of wind. She looked up to meet her conductor's eyes and nodded that she was ready. The tempo counted in and her right hand let rain fall.

#

Flushed, trembling after an encore – an encore! – Inez closed the door of her dressing room and leaned against it. The music was still filling her bloodstream and pounding through the small bones in her wrists. They hadn't planned for an encore, but the audience had kept applauding Ragnhildur's work. That last movement, played again, with Ragnhildur on stage, surrounded by the music and carried into the light of the Ljós movement, which went from sunrise to the shifting eddies of the Northern Lights.

She wanted to play it again. Right now. Exhausted and exhilarated, she wanted to play it again.

On the dressing table, her wrist phone rang. Even from here, she could see her parents' photo on the screen. She closed her eyes. They called after every performance. Letting out a breath, she opened her eyes and crossed the room. Swiping the phone, she sent the call onto the dressing room's wall screen.

"Hi Mom and Dad. Sorry that I haven't… Sorry."

They were beaming at the camera. Her mother leaned in close. "No, I'm sorry. We should have been there for you but, well… we weren't sure you wanted us."

"But we watched the stream!" Her dad pointed at the camera but probably meant their wall screen. "We're so, so proud of you."

"Six curtain calls! And an encore!" Her mother clapped her hands together and held them in front of her face in an almost prayer. "You were just… just splendid tonight."

Her chest filled as the last remnants of distress ebbed away. "Thanks!" They should have been here. "I'm sorry that I kept missing your calls. The time zones and rehearsal schedules…"

Her dad waved away her lies. "You needed to concentrate. I get it." He tilted his head to the side and cleared his throat. "So… do you have to keep wearing them?"

The warmth in her chest went cold. She opened her mouth to say that they had performances on the next three weekends. And also… she'd had the thumbs off to take showers. The five minutes it would take to have this call with her parents would be less time that that.

"Sure. I can take them off." She used her right thumbs to undo the strap on the left but getting the other one off was weird and clumsy. "So. There's apparently a deal with Icelandair. Do you want to come out for one of the other weekends?"

"The music was still filling her bloodstream and pounding through the small bones in her wrists"

"Oh, that would be lovely. If we won't be in the way."

She shook her head, rubbing the bare spot where the thumb should be. "We can do the Golden Circle." But she would have the thumbs on. "Or maybe when we're done with this run? Then I won't have anything to pull me away."

"Fantastic!" Her dad seemed to understand what she wasn't saying. That she would have the thumbs on for most of their visit. "That's even better."

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"Well, you go on now. I'm sure there are people who want to talk to you. We just wanted you to know that we were proud. Even if–" Her mother checked herself. "We were proud of you."

Her heart was full and heavy with a sort of yearning to be with her parents and a relief that they were not, in fact, here. Not yet. But when she applied for citizenship, this performance tonight would help.

When she got off the call, Inez rested her hands on the piano in her dressing room. The keys felt unfamiliar and her hand placement was weird and off. She rolled up an arpeggio and it was okay not having the left thumb, but the right… it felt like a note was missing. As if she had to stretch in ways that she should not.

Which was exactly what her parents had warned her about.

They were right. She had rewired her brain. Playing the piano now without the thumbs would feel like a loss.

Someone rapped on her door. She wiped her eyes – not because she was actually crying but just that she was over-emotional after the performance. "Come in?"

Ragnhildur stuck her head around the door. "Hello favorite person! Sóldís is taking us out to celebrate. With the benefactors." A tendril of her blonde hair had escaped its bun. "You are coming. Yes? There is talk of The Future which, I am not certain what it means, exactly, but I am certain that the immediate future involves very good cocktails at a very good club."

"Absolutely. Just give me a minute to grab my things." She grinned at the other woman. "Very good cocktails sounds like exactly the thing."

"Just don't spill it!"

"Ha!" She turned to the dressing table and picked up one of the thumbs. "I won't."

Inez put her thumbs back where they should be and went to find out what the future held in its twelve-fingered hands. ▮

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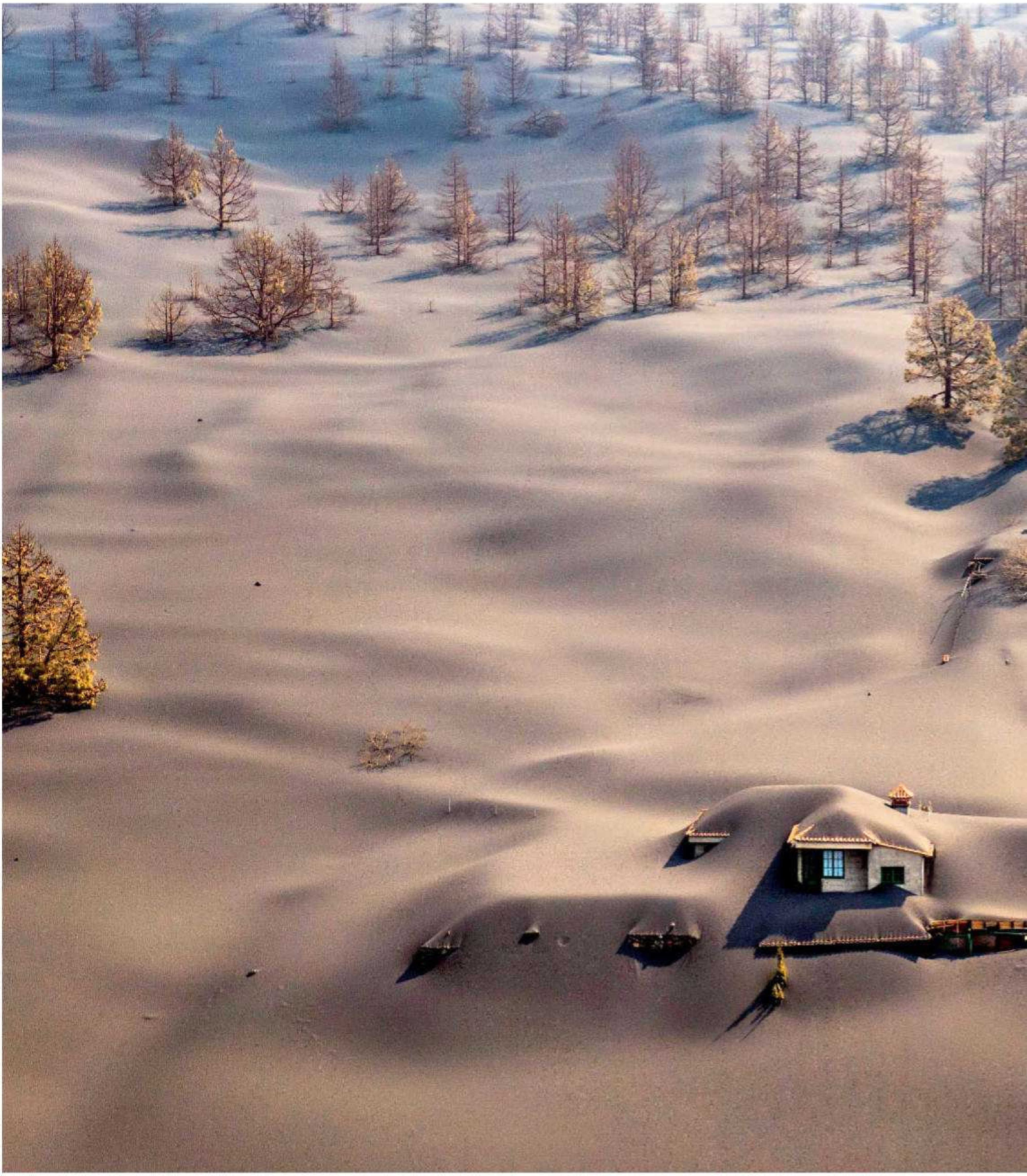

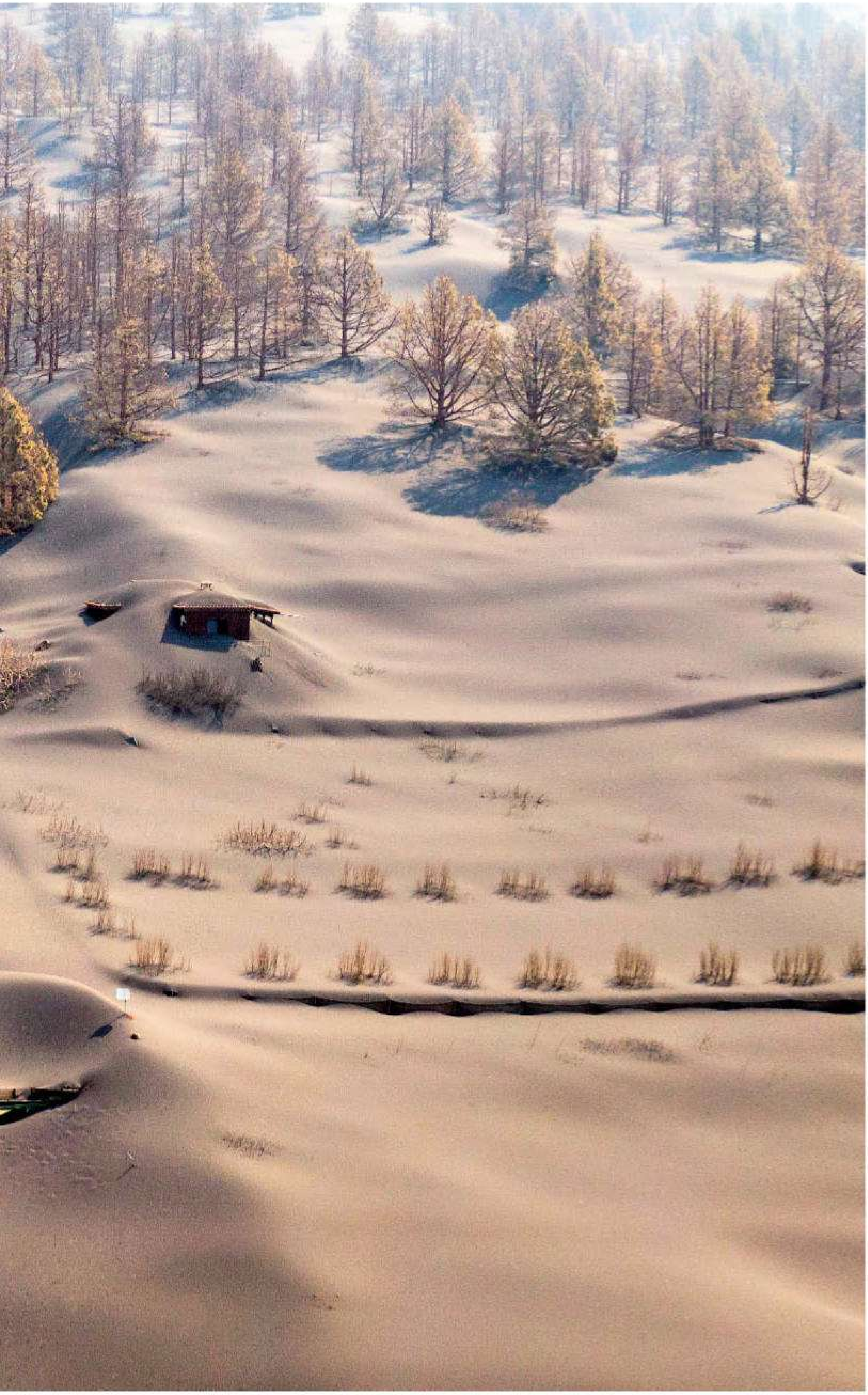

Blanket coverage

Photographer **Emilio Morenatti**
Agency **AP/Shutterstock**

THIS apparently wintery scene seems fitting for many at this time of year, if somewhat extreme. Yet this isn't snow. It is a deep layer of ash deposited by the Cumbre Vieja volcano on the island of La Palma in Spain's Canary Islands. The image was taken by Emilio Morenatti, chief photographer for the Associated Press in Spain and Portugal.

Since 19 September, Cumbre Vieja has been continuously erupting, forcing the evacuation of about 7000 residents and destroying around 2700 buildings. The activity has been explosive, spewing enormous amounts of lava, ash and gases such as carbon dioxide and sulphur dioxide into the air, and has been accompanied by ongoing earthquakes.

The Cumbre Vieja volcano last erupted in 1971, and scientists are trying to work out what is causing the current outburst. Signs that trouble was looming may have emerged as early as October 2017, when clusters of quakes, dubbed "earthquake swarms", were detected. Many more swarms occurred in the intervening years, but eight days before this eruption began, the number of earthquakes increased sharply, to several hundred every day.

The volcano's infrequent eruptions make it difficult to forecast future activity, but evaluating what is happening this time could help with future volcanic risk management in the region. ▮

Gege Li

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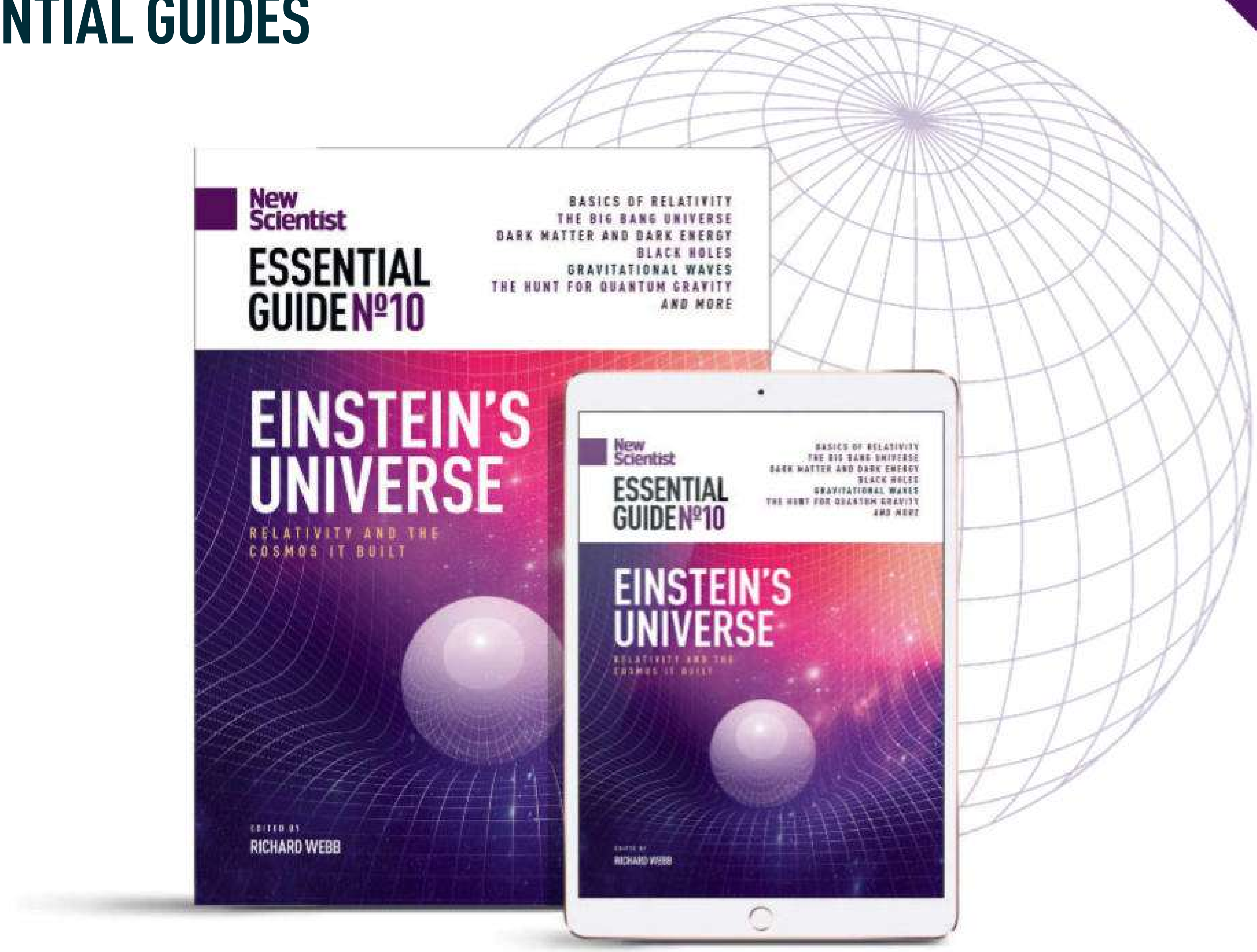

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Mirth and marvels

We come bearing gifts and good cheer with our 29-page festive features special, including monkeys on the high seas, a grand unified theory of snowflakes, cosmic smash-ups, a razor-sharp medieval monk, the microbes inside your cheese, a new kind of colour, beer of the future, why we laugh and much, much more...

On a raft and a prayer

Fresh clues could finally tell us if monkeys and other animals sailed across oceans on floating islands of vegetation, finds **Graham Lawton**

BRETT RYDER

IN DECEMBER 2016, Uwe Fritz at the Museum of Zoology in Dresden, Germany, was doing fieldwork in Colombia when something incredible crossed his path. While chugging across a vast expanse of wetland, he passed an enormous floating island complete with tall trees and a resident colony of howler monkeys. "Have you ever seen a howler monkey?" says Fritz. "They're huge! But the trees were large enough so the monkeys can permanently live in them. They do not swim." All told, the island covered an area about the size of two Olympic swimming pools.

Fritz later told a collaborator, Jason Ali at the University of Hong Kong. Ali's jaw hit the floor. "For me, it was just a random observation," says Fritz. "But he is the floating island guy. He has worked on them for years, but never seen one."

Ali is one of the leading advocates of one of the most controversial ideas in evolutionary biology: that the presence of certain species in certain places can only be explained by long-distance maritime voyages. The hypothesis, essentially, is that animals were carried across the ocean on rafts of vegetation and started afresh on the other side.

The sheer unlikeliness – some would say preposterousness – of this idea has always been an obstacle to its acceptance, and the arguments for and against the rafting hypothesis have sloshed back and forth for 160-odd years. But now, with floating islands in Colombia and fresh clues from the sea floor, both sides are claiming to have evidence that could finally see the idea sink or swim.

The rafting hypothesis is as old as the theory of evolution itself. In *On the Origin of Species*, Charles Darwin pointed out that the flora and fauna of the Galapagos Islands were clearly related to those of South America, while Cape Verde's were distinctly African (Darwin visited Cape Verde's main island Santiago in January 1832). His point was to discredit the belief that each species was a unique, divine creation, but he inadvertently launched the idea that the inhabitants of distant islands must have somehow blown in from the mainland.

Improbable as they seemed, epic oceanic voyages by animals clinging to logs or vegetation seemed the only possible explanation for the presence of certain species in certain places. At that time, scientists thought that the continents' positions were fixed, so alternative possibilities didn't readily present themselves.

As well as the Galapagos Islands and Cape Verde, there was the mystery of Madagascar. Despite being separated from Africa by the deep, fast-flowing Mozambique Channel, which is some 400 kilometres wide at its narrowest point, the island's fauna nevertheless have a clear African history. On top of now-extinct Malagasy pygmy hippos, these include three groups of living mammals with African ancestry: lemurs, tenrecs and mongoose-like carnivores such as fossas. Unlikely as it sounded, they must have crossed the channel.

Occasional anecdotal observations of ocean-going floating islands lent some credibility to the hypothesis. One of the most detailed comes from 1892, when the US Hydrographic

Office in Washington DC received reports of a stand of trees floating in the Atlantic Ocean. Described as "a piece of forest covering ¼ acre, topmost branches reaching at least 30 feet above sea level", it was sighted again later the same year, 1850 kilometres further north-east. What became of it after that isn't known.

Then along came plate tectonics, which holed the rafting hypothesis below the waterline. If continents moved around, and sea levels fluctuated to expose transient land bridges, there was no need to invoke implausible oceanic voyages. Animals simply walked to their distant homes and were then cut off.

But the rafting hypothesis didn't sink entirely. It began to resurface in the 1990s when new molecular dating techniques revealed that the reptiles and amphibians of the Greater Antilles – a group including the islands of Cuba, Hispaniola, Puerto Rico and Jamaica – had arrived in dribs and drabs long after the islands had drifted away from the mainland.

Favourable currents

Biogeographers then took a second look at other animals in far-flung places and surmised that they, too, had some questions to answer. Again, Madagascar loomed large. The new techniques showed that the ancestors of hippos, tenrecs, lemurs and fossas all colonised it long after it rifted from Africa 157 million years ago and that they all arrived at different times. There were no known land bridges. This has helped to reinstate long-distance over-water dispersal as the dominant theory, says Paul Mazza at the University of Florence in Italy.

We have a clear idea of how this "sweepstake colonisation" might happen, says Judith Masters at the University of Fort Hare in South Africa. Very occasionally, animals living in or near rivers get stranded on rafts of soil and vegetation ripped from the riverbank by flash floods. The rafts can be huge, and stocked with enough food and water for even quite large animals to survive for weeks. Some wash out to sea and get carried away on currents. The vast majority drift aimlessly and break up, and their passengers end up starving, dying of thirst or exposure, drowning or getting eaten by sharks. But very occasionally, a raft will catch a favourable current and make landfall on some distant shore. If enough members of a single species make it – especially if their number includes a pregnant female – then they may establish a new colony. Each of these possibilities is remote, but over geological time they stack up to become quite probable.

One leading proponent of this scenario is ›

Ali. He points out that the flora and fauna of distant islands generally consist of a fairly random selection of descendants of those found on the nearest bit of continent, which is exactly what you would expect if they arrived by chance. He also points out that the colonists tend to be small, hardy creatures such as lizards, shrews and, at a push, primates, which are better adapted to surviving a long voyage. There is a reason nobody ever claimed that lions or giraffes crossed the ocean on a mat of vegetation, he says.

But Ali and his fellow travellers do claim something that seems to stretch credibility: that 35 million years ago, monkeys rafted across the Atlantic Ocean. We know that the ancestors of the New World monkeys evolved in Africa around 40 million years ago, but then they suddenly pop up in South America 5 million years later – a seemingly instantaneous teleportation, in geological terms, across the then 1500 kilometres of ocean.

"Obviously it's very improbable, but you only need one crossing event," says Ali. There is good evidence that rodents also made the trip separately, he adds, and in any case it is hard to see any other way monkeys could have got there. "We see what we see. It is what exists," says Ali. In unpublished work, he has estimated that with a decent current, a raft could have crossed the Atlantic in about 14 weeks – just about long enough for a small primate to survive.

This doesn't float everyone's boat. "It's a crazy idea," says Mazza. "How can animals like monkeys cross an ocean without food and water, with exposure to salt, with overheating? It's virtually impossible. It's the same as saying that Martians transported them."

> **"Obviously it's improbable, but you only need one crossing event"**

The sheer implausibility also renders the geological time argument bogus, he argued in a 2019 paper. "We're told that what is impossible is made possible by millions of years," says Mazza. "This is like saying that if we throw ourselves from windows for millions of years, maybe somebody can fly. Piling up impossibilities and figuring that we end up with a possibility statistically makes no sense." Invoking rafting is grasping at straws, he says.

That isn't to say sweepstake colonisation never happens. Invertebrates, plant seeds and small vertebrates have more of a shot as they can probably survive for longer on smaller flotsam. After the 2011 Tohoku earthquake and tsunami in Japan, around 300 Japanese marine species were found on the shoreline of British Columbia having been carried on artificial debris. Some larger vertebrates, such as tortoises, crocodilians and possibly even hippos, may be able to float or swim.

Of course, sceptics can't just pour cold water on the idea. The presence of particular animals in certain faraway places still requires an explanation, so what have they got? "There must be some other more logical and more reasonable explanation," says Mazza. "Maybe we don't know enough about the geology of the sea floor."

For Madagascar at least, that could be the answer. According to a 2020 paper by Mazza, Masters and others, previously unknown land bridges between Madagascar and the African mainland rose and fell three times in the past 65 million years. The timing coincides with those difficult-to-explain colonisations.

A related possibility is stepping-stone colonisation, where animals make short hops along an island chain. If tectonics then erases the intermediate islands, this creates the illusion of a long-range oceanic dispersal, says Mazza. Another option, at least for more recent animal crossings, is that small creatures such as lizards were accidentally or deliberately transported by prehistoric humans. We know that our Stone Age ancestors were skilled seafarers, navigating across hundreds of kilometres of ocean to reach Japan 35,000 years ago and perhaps even sailing from South-East Asia to Australia 65,000 years ago.

What about the New World monkeys? Mazza says people are investigating that.

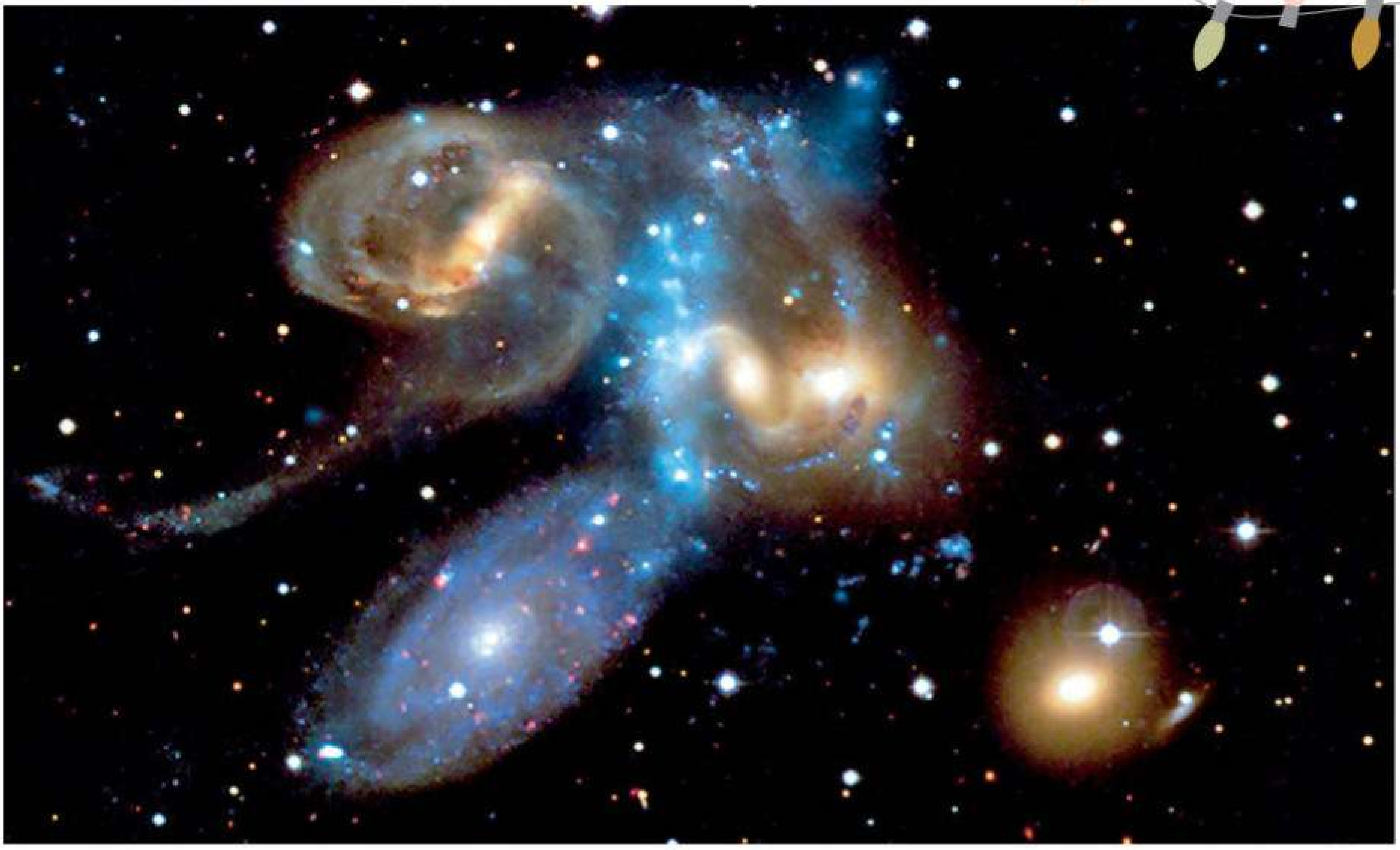
What would really help to settle the matter is a direct, unambiguous observation of a raft out to sea, preferably with animals on it. Floating islands are commonplace in the inland swamps of Colombia, says Fritz, and during the rainy season they are flushed into the Magdalena river, which flows into the Caribbean. Nobody has ever seen one go the distance, but Fritz says he believes it is possible. The one he saw looked like it would have been seaworthy for months.

To that end, Ali says he wants to tag some floating islands with GPS trackers to see where they end up. But with rivers around the world increasingly dammed and otherwise clogged up, the possibility of a raft ever making it out seems remote. There are two dams across the Magdalena. Rafts have also been seen (and filmed) on the Chagres river in Panama, but it now drains into the Panama Canal and there is no chance of a raft successfully reaching the sea. So if those cheeky monkeys are planning another epic crossing, they may have to wait a few more million years. ■

NICK GARBUTT/NATUREPL.COM

The ancestors of lemurs somehow crossed from mainland Africa to Madagascar

Graham Lawton dreams of escaping on a floating island



X-RAY (NASA/CXC/CFA/E.O'SULLIVAN); OPTICAL (CANADA-FRANCE-HAWAII-TELESCOPE/COELUM)

A galaxy passes through other galaxies in a group known as Stephan's quintet

Galactic ghosts

Intricate patterns in the movements of stars are revealing the epic collisions that shaped the Milky Way, finds **Thomas Lewton**

HUMANS have always been captivated by the Milky Way. To the ancient Greeks, it was a squirt of breast milk, while the Mayan farmers of Mesoamerica saw it as a growing maize stalk. Today, astronomers understand that what we see when we gaze up at the hazy streak of light stretching across the night sky is actually just one part of our host galaxy – one of four spiral arms emanating from an enormous disc of dust and gas that together contain at least 100 billion stars.

But even as we have traced our cosmic origins on the grandest scales, from the big bang to the growth of trillions of other galaxies entangled in vast webs, the history of our galactic backyard has remained opaque. It isn't for want of trying. The problem is that when you are inside something, it can be hard to see what is really going on.

Now, a clearer picture of how our galaxy, the Milky Way, came to look the way it does is beginning to emerge thanks to data gathered by the European Space Agency's Gaia satellite. Hidden patterns in the movements of stars have taken astronomers by surprise, unveiling in rich detail a turbulent history of cataclysmic collisions and aftershocks.

Some say that soon we will even be able to pinpoint the specific events that led to the formation of our sun – the reason we are here to ponder such things. "It's our heritage, a way of knowing ourselves," says Tomás Ruiz-Lara, an astronomer at the Institute of Astrophysics of the Canary Islands, Spain.

Over the past century, astronomers have sketched an outline of the Milky Way. We now know that it formed some 14 billion years ago, probably from clouds of gas and dust and smaller star clusters pulled together under gravity into a thin disc. We know that this disc is warped, with a thick, bar-shaped bulge at its centre. We also know that all of this is encapsulated in a spherical halo of stars and an ill-defined, even bigger halo of dark matter – the mysterious stuff that seems to hold galaxies together.

We know that we aren't alone, too. There are dozens of smaller dwarf galaxies orbiting the Milky Way, entangled in intricate and occasionally violent cosmic dances. Our best computer simulations suggest that mergers with bigger galaxies, several of them on a par with the Milky Way, were formative in our galaxy's youth. "But we don't know when or how or precisely how many," says Amina Helmi, an astronomer at the University of Groningen in the Netherlands.

›

DEEPOL BY PLAINPICTURE/NESTOR RODAN

The part of the Milky Way seen from Earth is one of four spiral arms

The Gaia satellite is now pulling this blurry history into focus by measuring the distance and motion of billions of stars up to several thousand light years away from the sun with exquisite precision. The information it is sending back to Earth amounts to a "huge treasure chest" for astronomers trying to piece together the details of the Milky Way's evolution, says Ralph Schoenrich, a theoretical astrophysicist at University College London.

In April 2018, when Gaia released its second tranche of data, Helmi and her colleagues threw themselves into investigating a particular subset: the fine motions of some 7 million stars as they wobble up and down in the plane of the Milky Way's disc. This is roughly akin to watching a human hair an arm's length away grow in 5 million times slow motion. Walking to her car one night, Helmi glanced at a data plot sent to her by a colleague, who was searching for patterns in "phase space" – an abstract, six-dimensional world that combines the 3D positions and velocities of stars. "I was like: 'Oh my god! What is this?' That plot was absolutely stunning," says Helmi.

The team had uncovered a weird snail-shaped pattern caused by something hitting the Milky Way's disc a few hundred million years ago. Based on existing computer simulations and observations of star streams, the most likely culprit was a dwarf galaxy called Sagittarius, which was known to have plunged through the Milky Way three times in the past. But no one expected an imprint of such an ancient collision to still be encoded in the motions of stars today. "That was genuinely a surprise," says James Binney at the University of Oxford.

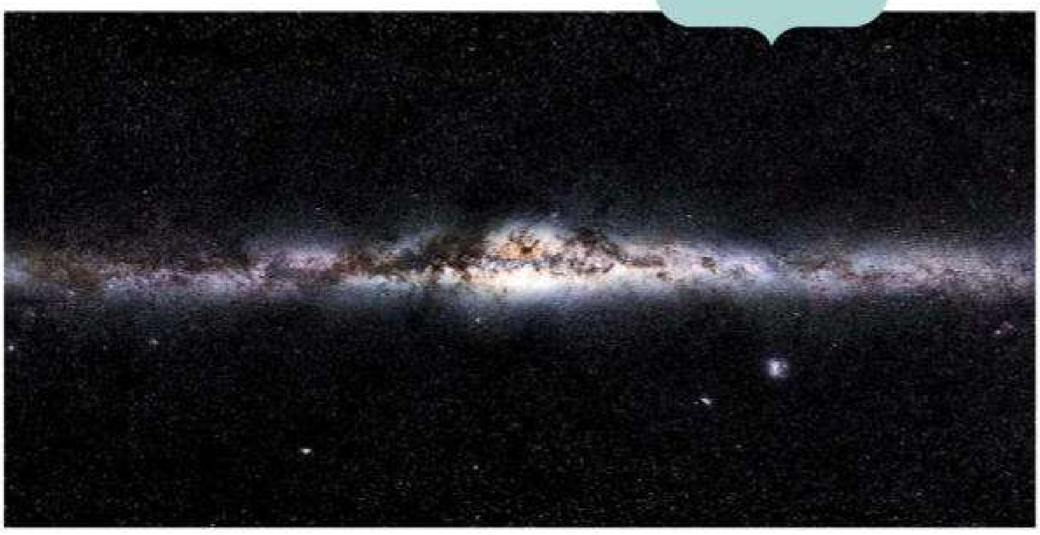
Astronomers are still wrangling over the precise origin of the snail shell. Theoretical models and computer simulations have since backed up Sagittarius as the prime suspect, but it was more likely to have been caused by one of the dwarf galaxy's earlier crossings a billion years ago, says Joss Bland-Hawthorn at the University of Sydney. "Sagittarius has been shedding a lot of mass along its orbit. Today, it's nowhere near massive enough to do any of this," he says.

Indeed, these days Sagittarius is a strung-out shadow of its former self, hurtling back towards the Milky Way as it traces the third leaf of its clover-shaped orbit. Eventually, like many galaxies before it, Sagittarius will become part of us, having profoundly shaped the Milky Way on its journey.

Regardless, the snail shell is one among many previously hidden patterns that show Gaia is ushering in a new age of "galactic seismology", says Bland-Hawthorn. No longer restricted to fossil records, we can now observe the faint tremors left behind by the impacts of intruders past – in the same way that we learn about Earth's hidden interior by watching how earthquakes propagate. Deciphering these tremors, astronomers are sketching a new panorama of the Milky Way and the riotous saga of how it came to be.

A decade ago, it was proposed that an impact with Sagittarius was the origin of the Milky Way's spiral arms – an idea that astronomers are beginning to test with Gaia data. There might even be clues to the true identity of dark matter lurking in this surprisingly dynamic galactic dance. The type of particles that make up dark matter – whether they are heavy or light, for example – would influence the orbits of dwarf galaxies like Sagittarius around the Milky Way and the patterns left in their wake. "Two years ago, if you had asked anyone in the field, they would not have thought that anything like that was possible," says Schoenrich.

As if all that wasn't enough, Ruiz-Lara



A map of 1.8 billion stars drawn from data from the Gaia satellite

ESA/GAIA/DPAC

suspects that Sagittarius may even be responsible for giving birth to the star that warms Earth to create just the right conditions for liquid water – and life – today.

Stars in a galaxy are a bit like people in a city, says Ruiz-Lara. From year to year, the number of people born fluctuates, and so does the city's population. "This is what we are trying to characterise with the star formation history," he says. "How many stars were born 10 billion years ago? How many stars are being formed right now?"

Ruiz-Lara and his colleagues were searching Gaia data for answers when another unexpected pattern emerged: three distinct bursts of star formation that coincided with the three passages of Sagittarius. Tantalisingly, one of these explosions of star births was calculated to happen between 4 and 6 billion years ago. "The age of the sun is 4.6 billion years," says Ruiz-Lara. "Can we say for sure the formation of the sun was triggered by this event? We cannot, but it's compatible. It could be that we are talking now because of this collision with Sagittarius."

When galaxies clash, shock waves emanate outwards, creating high-pressure belts of gas and dust that collapse into stars. Although we know that some groups of stars are formed in these violent collisions, it is much harder to say why specific stars appear where they do. The way to figure out the unique life stories of stars is to look for their families, says Ruiz-Lara. "We might find that our sun has a lot in common with a particular family of stars that was caused by a certain event."

Joining up the dots in this way requires huge data sets, which is why Gaia measurements are now being combined with data from Earth-based telescopes that have been collecting detailed information on the chemical fingerprints and brightnesses of tens of millions of individual stars.

Similar techniques are revealing previously obscure primordial galaxies such as Gaia Enceladus, which is a million times more massive than the sun and is thought to have merged with the Milky Way in its youth about 10 billion years ago. We are just beginning to untangle these mergers, like archaeologists uncovering cultural artefacts from the Roman and Viking invasions of Britain, says Ruiz-Lara.

Yet the trove of intriguing patterns that the Gaia satellite is unearthing is also raising difficult questions. Few thought that the Milky Way would still be recoiling so blatantly from its collisions with minor galaxies billions of years ago. "We have to proceed more cautiously," says Binney, because we don't yet have the tools to model this responsive and dynamic galactic ecosystem. "You have to think holistically in terms of the whole beast."

Indeed, Gaia is a stark reminder of how hazy our underlying picture of the Milky Way is. Until this develops, it is hard to be sure what the new data glut is telling us, and these notions of primordial mergers, spiral arms and the birth of the sun are by no means certain.

Other ideas are certainly conceivable. Sergey Khoperskov at the Leibniz Institute for Astrophysics Potsdam in Germany and his colleagues, for example, have proposed that the snail shell pattern is an echo of the Milky Way's central bar buckling long ago. "I wouldn't be surprised if somebody comes up with a new model tomorrow that says this Sagittarius thing is junk and there's another explanation," says Chervin Laporte at the University of Barcelona in Spain.

> **"Data from the Gaia satellite is ushering in a new era of 'galactic seismology'"**

Astronomers are eagerly awaiting Gaia's next data release in the first half of 2022 for more clues. Pushing deeper inside the Milky Way, the data will offer a much bigger and more representative sample of our galaxy's stars, offering new information about their temperature, size and chemical composition, alongside their precise positions and movements. The phase-space data – in which the snail shell was found – will also increase five-fold, revealing patterns in star movements in finer detail. Helmi expects there will be many more patterns hidden in the ebb and flow of the Milky Way.

No one expects definitive answers any time soon. Theoreticians are only beginning to grapple with the mind-boggling complexity of our shape-shifting galaxy. "We'll need 20 years to understand the ESA Gaia data," says Schoenrich. But at least now we can begin to piece together the finer details of how our home galaxy came to be. ▮

Thomas Lewton is watching this space

A whiff of the past

Ambergris isn't just an ingredient of luxury perfumes, finds **Claire Ainsworth**

THEY say, where there's muck, there's brass. Anyone who has stumbled upon ambergris will confirm this. The weathered whale excrement is extremely rare, but it can be found on beaches in many parts of the world. It is unprepossessing: dusty grey or brown with the faintest whiff of earth and sea, mixed with something unfathomably animal. Yet this stuff is so prized by perfume-makers that a lump the size of a human head could fetch you £50,000 or more.

Traditionally used to boost the staying power of scents, these days a synthetic alternative means that ambergris is found only in some luxury fragrances. But now scientists have discovered that it harbours another treasure. Adrift in the oceans for decades, even centuries, before washing ashore, each lump is a message in a bottle from a long-departed whale. It holds clues about the lives of these animals before whalers came to plunder them. "There's really quite exciting potential to look at the impact of whaling on whale health and diversity," says Ruairidh Macleod at the University of Cambridge.

Ambergris also contains historical information about the oceans, especially the marine species foraged by the whales that produce it. It could even give insights into how these animals might respond to the challenges they face as a result of climate change.

Ambergris usually makes landfall after a long voyage, originating as black, waxy lumps in a sperm whale's colon. Nobody knows exactly why it forms. It may encase the sharp beaks of the squid that the whales prey on to stop them damaging the gut, or it may simply be a quirk of metabolism. The fresh stuff, reeking of faeces, has much less value than ambergris matured by a long soak in the sea. This latter form, known as jetsam ambergris, is composed chiefly of ambrein, an organic chemical capable of stabilising volatile scents, which is what made ambergris so sought-after by perfumiers. But it is ambrein's ability to repel water and resist decay that first drew the attention of Macleod and his Cambridge colleague Matthew Collins. They realised that ambergris could encase DNA and protect it from the elements. What's more, it could do this for centuries: in 2019, a team led by chemist Steven Rowland at the University of Plymouth, UK, carbon-dated a collection of ambergris to show that some lumps had been in the environment for around 1000 years.

Sperm-whale speciality

In a preliminary study, Macleod and his colleagues succeeded in sequencing stretches of DNA from Rowland's ambergris collection. This confirmed what many had suspected but never been able to show, namely that ambergris is produced by sperm whales. Now, the researchers want to sequence the DNA in ambergris more thoroughly, to read the history hidden in the whales' genomes. Studies of ancient DNA from other marine mammals show this approach can paint a surprisingly detailed picture. For example, in 2019, team member Morten Tange Olsen at the University of Copenhagen, Denmark, and his colleagues combined analyses of DNA from walrus bones with historical and archaeological information to explore why walruses disappeared from medieval Iceland. This revealed the existence of a genetically unique population that appears to have been hunted to oblivion by Norse settlers during the 11th and 12th centuries. ”What really surprised me is how far back in time humans have had an impact on marine ecosystems," says Tange Olsen.

In the 20th century, commercial whalers slaughtered at least 3 million whales. Studies of ambergris DNA could help researchers assess the relative sizes of pre-whaling sperm whale populations and their genetic diversity. Comparison of ancient whale DNA with modern samples might also hint at how natural selection has shaped these animals.

PETER CROWTHER

In search of floating gold

Ambergris washes up worldwide, including in East Africa, India, Australia, New Zealand, the Bahamas, parts of northern Europe, the east coast of the US and the south coast of Chile. But before you go beachcombing, check local laws as some countries prohibit the export, sale or even possession of ambergris.

After that, it is down to luck and scouring the shoreline or, if you are so inclined, training a dog to help sniff it out. Ambergris is rare – produced in the gut of only a few sperm whales – and easy to confuse with more common items of jetsam, such as congealed cooking oil. It is lumpy and uneven in shape, feels waxy and hard, but can be scratched. Its colour and smell (and value) vary by how long it has been at sea. The least valuable kind is black and foul smelling. White ambergris (the most valuable) and brown are older. They have a sweet aroma with musky, earthy and marine notes, plus hints of forest floor.

There are ways to test a find, but this is better left to experts. Last year, a woman who tested a possible piece of ambergris by poking it with a hot needle, ended up with a fireball in her kitchen. Firefighters told her the lump was probably an unexploded grenade from the second world war.

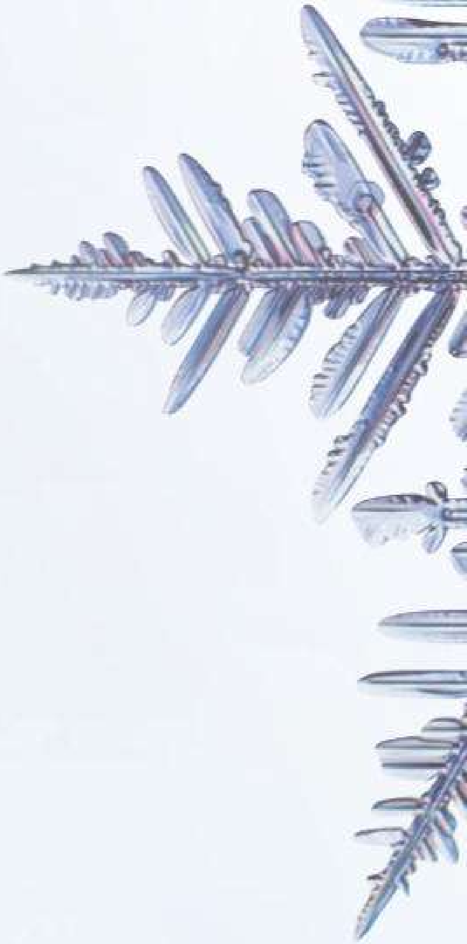
But ambergris doesn't just contain DNA from sperm whales. Macleod and his colleagues found patchy sequences from a multitude of other organisms, too, ranging from bacteria and other microbes to intestinal worms and armhook squid, the whales' usual prey. Exploring the microbial sequences in more detail could allow researchers to get a handle on the gut microbiomes of past sperm whale populations, which in turn could reveal how the pressure of whaling affected their foraging strategies and microbiome diversity, says Macleod. Sequences from the worms and squid could reveal knock-on effects on prey animals. "It shows the kind of ecological ripples resulting from killing lots and lots of whales on all these other species," he says.

Studying whale digestion and the role of their gut microbiomes can even help us understand our planet's biogeochemistry and climate. "Whales are consuming a large amount of carbon every day," says Amy Apprill at Woods Hole Oceanographic Institution in Massachusetts. She and her colleagues have been working with Indigenous Alaskan subsistence hunters to see how microbes in the guts of bowhead whales influence the digestion of wax esters, a carbon-rich chemical found in species the whales eat. Others have shown that whale excrement creates plumes of nutrients, such as nitrogen, in the water column, nurturing the growth of plankton that consume carbon as they photosynthesise. As well as storing carbon in their bodies while living, whales often take it with them in death, sinking to the deep ocean where their carbon can remain in sediments for centuries.

Understanding more about whale gut microbiomes will also help scientists keep track of how modern populations are coping with climate change and other stresses. "The microbiome might be a really useful metric for health in these animals," says Apprill. Ambergris would provide "an amazing baseline" to better understand and add context to data from today's animals, she adds.

Sadly, we are unlikely to see a return of the pristine oceans of the pre-whaling era. But ambergris could help us understand how these charismatic beasts might survive a future in the noisy, warming world we have created. For that reason, at least, it would be priceless. ∎

Claire Ainsworth is having a whale of a time



A grand unified theory of snowflakes

Snowflakes can form in two different ways to produce myriad shapes, but no one understood exactly why – until **Kenneth Libbrecht** investigated. He tells Joshua Howgego about his frosty discoveries

SNOWFALL in Pasadena, California, is so rare, it's almost unheard of. Except, that is, at the California Institute of Technology, where Kenneth Libbrecht can conjure it up using the world's most sophisticated snowflake-making equipment.

As a physicist, Libbrecht has tackled some fairly epic questions, like the nature of gravitational waves and the internal workings of the sun. But he also has a delightful sideline in the science of snowflakes, which are far more complex and mysterious than you might think. One of the biggest unanswered questions about them is why they appear to come in two distinct types.

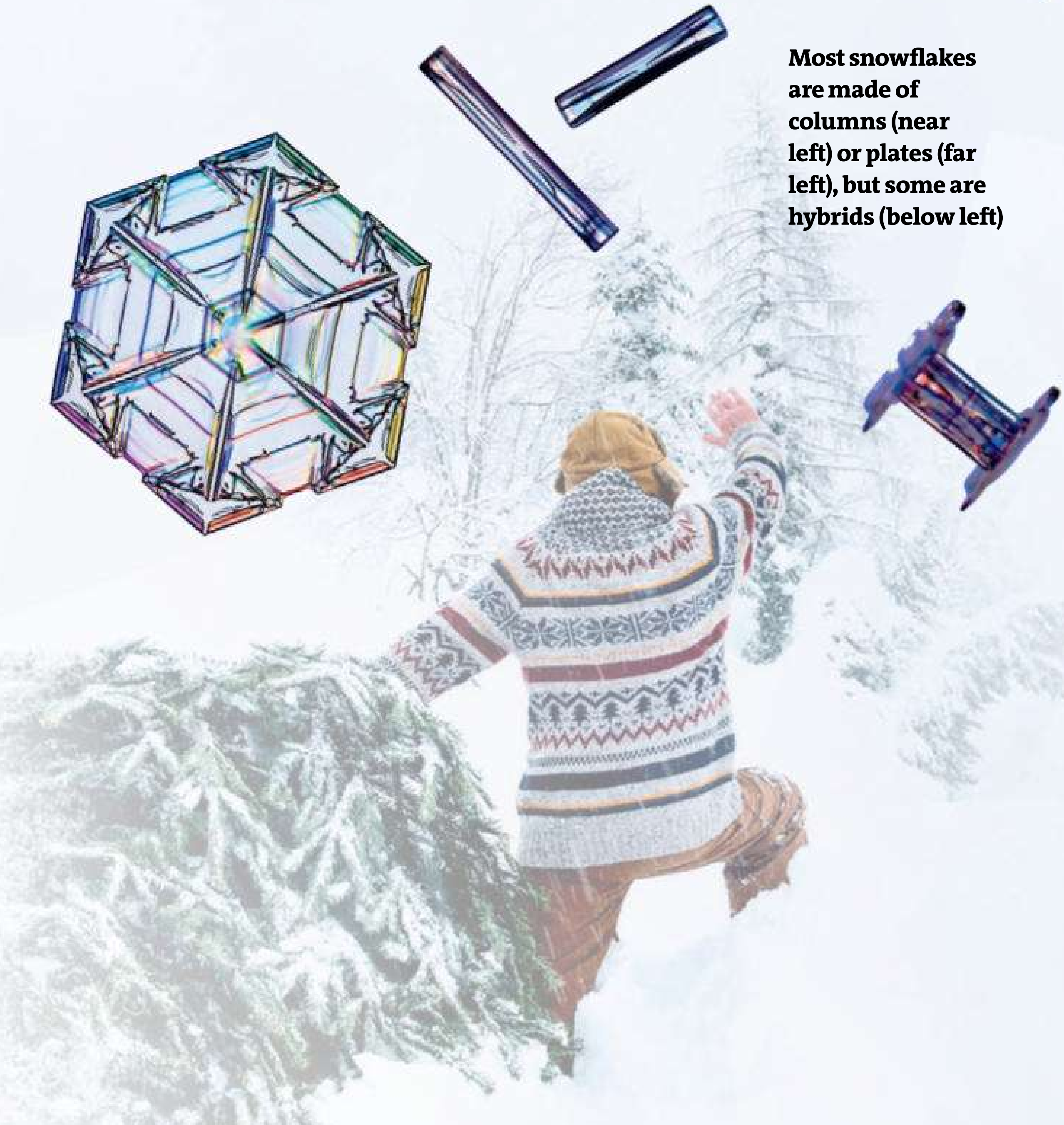
Libbrecht went on a 20-year odyssey to solve this mystery. Recently, he published the fruits of that journey in the form of a monograph that runs to more than 500 pages. It contains a kind of grand unified theory of snowflakes, explaining for the first time how and why they grow into the delicate shapes they do.

Joshua Howgego: What got you interested in snowflakes?

Kenneth Libbrecht: One day I was chewing the fat with one of my students and we got talking about how crystals grow and take on shapes. We started thinking about what we could study in this area and I thought: well, water would be cheap and easy. Then I thought: actually, that would be the physics of snowflakes, I wonder how that works? Apropos of nothing – I was just curious – I started reading up on research on snowflakes and I found it really fascinating.

What was the big question about snowflakes?

The standard snowflakes you see in holiday decorations – six-pointed, thin and flat – well, that's not the way they always form. As well as thin, hexagonal plates, they can grow into tall, hexagonal columns, like the shape of a pencil



Most snowflakes are made of columns (near left) or plates (far left), but some are hybrids (below left)

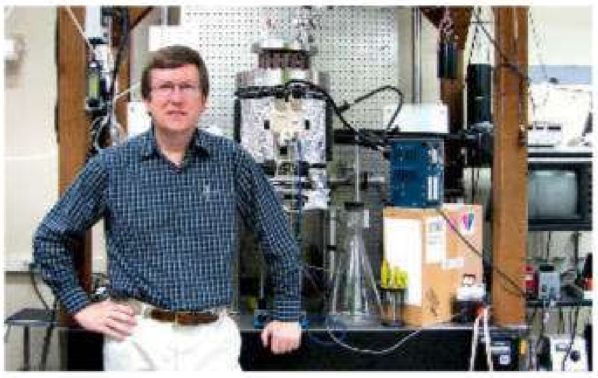
HANS HUBER/PLAINPICTURE; SNOWFLAKES COURTESY OF KENNETH LIBBRECHT.

> **"I can turn knobs to control the conditions exactly, so I can get these designer snowflakes"**

in miniature. It was discovered in Japan in the 1930s that these two forms of snowflake will form at different temperatures. Plates will form at around -2°C, columns at about -5°C and then plates again at about -15°C. It's such a crazy pattern that it flops back and forth like that. I really wanted to know why it happens, but it turned out there was no answer – it was a complete mystery.

How did you investigate this conundrum?
I decided the way to answer this question was to systematically grow a lot of snowflakes in different conditions and measure their growth. This was 20 years ago, and for several years I kept hitting problems and made no progress. I eventually figured out the whole experiment has to be enclosed in a box. You add in water vapour, but the conditions, like temperature and pressure, have to be precisely controlled. I have all these little rods going into the box that I use to push things around and turn things on and off. Then I could grow crystals – mostly I grew ones that are smaller than the width of a human hair and then studied them under a microscope. If they get too large, they are too complicated in shape to study easily.

You recently published what has been called a grand unified theory of snowflakes.
People had always thought that if you have a flat surface in a crystal, it always grows in the same way under given conditions. What I found is that in snowflakes, the size of the surface matters quite a lot. If you imagine a hexagonal, plate-like snowflake, it has two wide surfaces and then six much thinner surfaces around the edge. It turns out that those thinner surfaces grow much faster than the broader surfaces, and this creates a runaway effect where you get thinner and thinner plates. The fun thing is that this trend reverses – at certain temperatures, it's the wider surfaces that grow faster, and so you get column-like crystals.



Kenneth Libbrecht in his snowflake lab

To understand this fully, you need to dig down into the details about the molecular structure of the ice crystal surface and how it changes with temperature on different surfaces. So far, my model seems to fit all the data, so it is encouraging that at least some of the mystery has been solved.

Does your work tell us anything about what snow would be like on other worlds, such as Saturn's icy moon Enceladus?
The diffusion of water molecules through the air affects snowflakes' growth in a way that reinforces the molecular effects to create the thin edges seen in plate-like and hollow-column crystals. When I grow crystals in a vacuum, none of this happens. So, yeah, there would be differences in snow on other planets. If there's no atmosphere, you are going to get blocky crystals, but at high pressure you would get incredibly thin ones. Of course, the chemistry of the atmosphere could change this, too, in ways that are hard to predict.

You have also grown two identical snowflakes. I thought that was supposed to be impossible.
This started when, early on in my snowflake work, I realised there were no good videos of snowflakes growing. I wanted to make one showing a perfect-looking crystal. Eventually, I worked out how to grow crystals on a fixed support and film them. They looked so much better than crystals that fall from the sky. They were crisper, sharper. Real snowflakes have had kind of a hard life, falling through the atmosphere and banging into other flakes. They have also begun to evaporate, so the edges are always a little rounded.

In the lab, though, I can turn knobs to control the conditions exactly – I can even change things slightly to make the growing crystals branch – and so I can get these designer snowflakes. Then I realised that if you grow two snowflakes next to each other in the box and grow them at the same time, under the same conditions, they come out very similar. Everybody seems to have heard this old adage that no two snowflakes are alike, but then this crazy person is making snowflakes that are alike.

What kinds of questions are still unanswered when it comes to snowflakes?
My model is very complicated. But it makes a lot of predictions and I want to test those out, see what happens and hopefully refine the model. One of the predictions is that interesting things might happen to snowflakes close to their melting point. You might see what's called pre-melting, where most of the snowflake is a rigid crystal, but on the surface the molecules get disordered. I've been trying to explore that. I'm also trying to make larger crystals; I'd like to make the world's largest snowflake. For no particular reason… there's just always something new to try.

When you go out in the snow these days, do you see it in a new light?
I grew up in North Dakota, where it gets very cold and we have a lot of snow. I used to see six-pointed star flakes, large ones, but I didn't know any of this stuff. Now I know a lot better what to look for. I'll go out and have a magnifier and be looking for different kinds of flakes – like capped columns, for instance, which are like a special hybrid of the plate and column types. I call it snowflake watching. The funny thing is, my wife is a botanist, and when we go out together she's always looking at the different plants – but they all look like weeds to me. ▮

Joshua Howgego denies rumours he is a delicate snowflake

Cheeseomics

We have been making cheese for millennia, but researchers are only just getting to grips with the hidden world inside every block. **Alison George** investigates

WHEN it comes to finding new and exotic species, there is no need to travel to the rainforest or trawl the deep ocean. Just open your fridge. The cheeses in there contain a wealth of surprises, if you look closely enough.

Although cheese production began at least 7000 years ago, we are only just beginning to understand what is really going on in this complex ecosystem that we delight in devouring. "Cheese is a fascinating ecological niche," says Paul Cotter, a microbiologist at food and agricultural research body Teagasc who is based in Cork, Ireland.

New work on the cheese microbiome is revealing a riot behind the rind, with complex interactions between a diverse array of bacteria, moulds and yeasts helping to create characteristic flavours and textures.

"There are a lot of microbes that we're eating every day on some of our favourite cheeses, and we know incredibly little about what they're doing to drive the flavour of those cheeses," says Benjamin Wolfe at Tufts University in Massachusetts. Understanding this better will not only help control the flavours of existing cheeses, but also help us develop tasty new ones.

Here's a tour of some of the surprises hidden in your cheeseboard.

Exotic menageries

Cheeses are dominated by bacteria that digest the main sugar in milk, lactose, and turn it into an acid. But they are also home to a menagerie of other microbes that develop as cheese matures, and exactly how many organisms cheese contains is only just being revealed.

Studies using gene-sequencing technologies keep finding new bacteria, some previously unknown to science. A 2020 analysis of four different Cheddars, for example, found they were home to 159 different strains, only 16 of which were common to all.

One surprise has been how many bacteria found in cheese originate from the oceans. "We find them again and again," says Wolfe. "We have no idea really what they're doing to affect the flavour of cheese and we don't know how exactly they're getting to the cheese." The presumption is that they catch a ride in the brine the cheese is washed in.

One particularly exotic salt-loving marine bacteria found in cheeses is *Halomonas*. "Some are more extreme in terms of the levels of salt they can cope with" says Cotter. "They're more typical of the Dead Sea." The challenge now is to figure out how these microbes contribute to the array of compounds that create cheeses' flavours.

Going mouldy

Eating mould may not be your idea of fine dining, but when it comes to cheese, it is a prized ingredient. The most famous moulds are *Penicillium roqueforti*, responsible for the blue veins in Roquefort and Stilton, and *Penicillium camemberti*, which creates the fuzzy white rind of Camembert and Brie.

Two recent studies by researchers in France revealed how these fungi have been domesticated from the wild variety, in the same way that humans bred dogs from wolves by selecting favourable characteristics.

P. roqueforti has been domesticated twice. The first strain is slow growing and used only in the production of Roquefort, whereas a more recent domestication is responsible for a faster-growing strain used in all other blue cheeses.

P. camemberti has also been tamed twice: first in ancient times, when a wild, blue-green fungus was domesticated to

BENEDICT FLANAGAN

produce the grey-green mould used to make many cheeses, such as the Golot cheese of Turkey, and again in around 1900 to produce the characteristic white mould used in Camembert.

In the cheese ecosystem, moulds can work with other organisms to form particular flavours and textures. In Stilton, for example, *P. roqueforti* teams up with a yeast called *Yarrowia lipolytica*, known for its ability to break down lipids and proteins. This boosts the number of ketone aroma compounds, characteristic of smelly blue cheeses.

Gene-swapping orgies

The cheese on your plate is a den of gene-thievery. In the thousands of years since cheeses were first created, the microbes that make them have been rampantly swapping genes as they evolved to survive in this new environment.

One study by Wolfe and his colleagues of the genomes of 165 species of bacteria associated with cheese found that 80 per cent of them had acquired genes directly from others through a process called horizontal gene transfer. Many of these genes were involved with scavenging iron, a rare commodity in cheese. “Iron is incredibly limiting in this environment,” says Wolfe. “The winners are really those that have the ability to quickly find the iron.”

Warfare

It is a battle for survival in cheese, which means organisms need some weapons up their sleeves. A 2020 analysis by Cotter and his colleagues of the microbiomes of 55 artisanal Irish cheeses revealed that around 20 per cent of microbes in those cheeses contain genes for compounds called bacteriocins that kill their rivals. This is far higher than the 13 per cent found in our gut, for example, as well as other environments. “We were a bit surprised,” says Cotter.

Another inside-the-rind evolutionary arms race involves bacteria and viruses. About 20 per cent of the organisms living in cheese are bacteriophages, viruses that infect bacteria. But Cotter and his colleagues’ study showed that bacteria are armed with a defence mechanism called CRISPR to destroy bacteriophages, while the viruses are equipped with anti-CRISPR proteins to dodge these attacks.

> **“The rind, from an ecological perspective, is particularly fascinating”**

The top dogs of the cheese microbiome are fungi. “In these communities where you have both fungi and bacteria living together, the fungi really seem to be the drivers of the interactions,” says Wolfe. “We’ve seen examples where the fungi are wiping out the bacteria through the production of antimicrobial compounds.”

But fungi don’t always win. On the rinds of certain cheeses, such as Milbenkäse, produced in Germany since the Middle Ages, fungi are preyed on by cheese mites.

The bit you throw away

The rind, from an ecological perspective, is particularly fascinating. It acts not only as a barrier, but as a controller for the microbial action within. “As the rind grows, it releases enzymes that break down the milk and produce a lot of the flavours that we enjoy,” says Wolfe.

In Camembert, for example, the characteristic surface mould *P. camemberti* produces ammonia, a key cheese flavour molecule. This diffuses into the centre, increasing the pH and ripening the cheese by degrading the milk protein casein.

But the big question is: should we eat the rind? The answer depends on what kind of rind it is, and there are three main types.

You have the fuzzy white ones found on cheese such as Brie, and the sticky, pungent ones found on cheeses that have been washed in brine, wine or beer, such as Gruyère. These might taste “funky”, says Wolfe, “but you can eat them for sure”.

The third type is known as natural rind. You might find this on blue cheeses or cloth-bound Cheddars, resembling lichen growing on the surface.“That’s more of a functional rind, to help control moisture loss and prevent bad microbes from growing on the surface and is not there for flavour,” says Wolfe. “It’s totally fine to it eat it, but I tend to cut it off. ▮

Alison George is feeling gouda

Animal magic

If you can trick a bird or an ape, what does that tell you about their minds, wonders **Sam Wong**

IN HIS right hand, Elias Garcia-Pelegrin holds a worm. He pretends to grab it with his left but, while his fingers obscure it, he lets it drop back into the right – a classic sleight of hand called the French drop. Garcia-Pelegrin, who began performing magic when he was a student, has fooled countless people with this trick. But today's audience isn't buying it: Stuka the Eurasian jay moves her beak towards his right hand, which he opens to give her the treat.

Comparative psychologists have often employed deception to explore how animals think. For example, they have used boxes with false bottoms to switch one type of food for another, studying the reactions of dogs and apes to understand how they form mental representations of hidden objects. But the French drop experiment is something new. It is part of the first study to explicitly compare how animals and people react to magic tricks designed to fool humans.

Such illusions offer a fascinating window on our minds: they highlight gaps in our perception and attention that magicians exploit to disguise what is in front of our eyes. But what about other animals – do they fall for the same tricks we do? Could their susceptibility to magic tricks highlight flaws in their perception, or even reveal kinds of intelligence we didn't know they had?

"The interesting thing is the comparison with us," says Garcia-Pelegrin at the University of Cambridge. "Once we have the theory of why a trick works on humans, we can see why it works, or not, on another species, and that tells us about their vision system, their attentional system, their perceptive system and maybe their metacognitive systems. A lot of magic capitalises on you thinking about thinking."

Eurasian jays are a fascinating choice for this research because they are very different from humans yet are capable of feats resembling magic tricks. Like crows and other members of the corvid family, they hide food to retrieve later. If another jay is watching, they may pretend to stash their food in multiple places so that the observer doesn't know where it is – rather like a magician performing a cups-and-balls trick. They can even hide items in a throat pouch, just as magicians use secret pockets.

These acts of deception demonstrate sophisticated cognitive abilities. Clearly jays are able to think about other birds' knowledge and intentions, a skill that psychologists call theory of mind. They must also have good memories to recall the locations of their caches, and be able to plan for the future.

Great expectations

Mental time travel, the ability to remember the past and anticipate the future is a key part of how magic tricks fool us, says Nicola Clayton at the University of Cambridge, who heads up the lab in which Garcia-Pelegrin works. "Everyone knows magic is about perception, ›

EMILE THE ILLUSTRATOR

New Scientist video
Watch jays being duped on our YouTube channel
youtube.com/newscientist

but what's more interesting is what it reveals about memory and mental time travel," she says. "If you don't remember and don't have a subjective experience of remembering so that you question your memory, then magic effects wouldn't work. That's our thesis."

But if Stuka is capable of mental time travel, why wasn't she fooled by the French drop? When humans watch the trick, we assume that the left hand is grasping the worm. But jays lack opposable thumbs, so they don't have the same expectations we have about how hands operate. "I expected jays not to be fooled by the French drop because they don't have hands," says Garcia-Pelegrin. The way that birds reacted to another of his tricks was more surprising.

This time, Garcia-Pelegrin held the worm in his right hand, then quickly tossed it into his left before closing both hands. The motion was too fast for a human to see, but what about Stuka? She leaned towards the magician's right hand again, only to discover that it was empty. "I did not expect jays to be fooled by the fast pass," says Garcia-Pelegrin. "Our vision system is not adapted to rapid movements, but birds are experts at seeing fast."

He suspects jays are duped for another reason. Birds can choose to pay attention to information from one eye or both, but preferentially use one because that gives them better resolution. It may be that when they see the fast hand movement, they switch from monocular to binocular vision and miss the worm's transfer during the change. "We hypothesise that rather than a perceptive blind spot, it's an attentional blind spot," says Garcia-Pelegrin.

Clayton, who is a leading authority on corvid intelligence, became interested in what magic can tell us about animal minds when she began collaborating with Clive Wilkins, an artist and magician who is also her tango partner. "Magic is really good at showing us the roadblocks in our thinking, the ways in which we're short-sighted," says Wilkins. "One of the ways is that we anticipate what the future is going to be before it has arrived. Magicians know this. They begin a movement, and while people are in a revelry of thinking they understand what will happen, they use that blind spot to do something completely different."

To see if jays have a similar cognitive roadblock, Clayton's group used a version of the cups-and-balls trick. Under the cups, there are either peanuts – a second-rate snack – or the birds' favourite treats, cheese or worms. If they lift a cup to find cheese or worms when they are expecting peanuts, they are pleasantly surprised. If they expect worms and discover peanuts, they throw the cup across the room seemingly in a tantrum.

These reactions demonstrate a knack for mental time travel, says Clayton. "The jays have a memory of what they think happens, then something else unfolds that reveals it didn't happen in the way they thought and that's why it's surprising. It's about questioning reality." Such abilities have been seen in only a few other bird species and apes, but, perhaps surprisingly, some invertebrates show impressive future planning skills too. Research published last year reveals that if cuttlefish know they will get their favourite food (shrimp) at dinner time, they will eat less crab at lunchtime.

MICHAEL POINSIGNON/GETTY IMAGES

Jays deceive each other in the wild, but aren't fooled by some human magic tricks

"Magic is really good at showing us the roadblocks in our thinking"

Clayton's team plans to follow these jay studies by testing sleight-of-hand tricks on other animals. Will monkeys with opposable thumbs be more easily fooled by the French drop? Will raptors with forward-facing vision pick up on a fast pass between hands?

Falling for magic tricks is one thing, but do they also amaze and amuse animals as they do us? Some videos posted online suggest they do: in one, an orangutan literally falls to the floor laughing. And Clayton thinks that other great apes could be entertained by magic provided the trick doesn't leave them feeling they have been cheated.

But Garcia-Pelegrin isn't so sure. "Think of magic as a social contract. You allow me to make a fool of you for your own benefit. That, in itself, requires a lot of theory of mind," he says. Besides, apes usually don't respond well when their expectations are violated. But he would love to be proved wrong. "If someone can show me that an orangutan is having a great time while seeing magic and show it scientifically, I'll be the happiest man on Earth." ▮

Sam Wong can make tasty snacks disappear

Trouble brewing

Climate change is shaking up the hops that give beer its flavour, finds **Chris Simms**

JEAN/STOCKIMO/ALAMY

Wicked weed: freshly harvested hop flowers

WATER, malted barley and hops. It is the classic recipe for the world's favourite intoxicant. According to a law declared in 1516 in the German state of Bavaria, a place that likes to see itself as beer's spiritual home, those are the only three ingredients it may contain – the yeast that converts the sugars in the barley to alcohol being out of sight and out of mind back then.

Today's craft beer revolution takes such strictures less seriously, with new and exotic brews catering for all manner of tastes. But one ingredient remains a constant – indeed the fulcrum – of good beer. Hops give beer the bitterness that counterbalances the sickly sweetness of the fermenting grain and imparts subtle flavour tones that distinguish one brew from another, all while acting as a natural preservative.

That is reason enough to declare the hop one of the world's most important, if often overlooked, plants. Yet trouble is brewing, with a perfect storm of changing tastes and changing weather contriving to shake up its cultivation. The question frothing on many a lip now is whether an ale and hearty future for the hop can be assured.

Hops weren't always so universally beloved. In England, they were once dubbed the "wicked weed", and traditional ales were brewed without them. It is a myth that Henry VI once tried to ban them, although the city of Norwich did in 1471, as it tried to defend the purity of yeoman English ale in the face of perfidious hopped continental imports. Before hops became the brewer's undisputed best friend, all manner of botanicals were employed to flavour beer (see "Rooted in history", page 67).

The hops that are used in beer are the flowers, or cones, of the hop plant, *Humulus lupulus*. Perennials that can live for decades, these are twining "bines" – plants that grow by spiralling in a helix around a support – that › can reach some 5 metres up wires in hop fields or ramble through hedgerows. Compounds called alpha acids in the hop cones produce their characteristic bitterness, but other constituents, such as beta acids, essential oils and flavonoids, mean hops can also add citrus, grassy, floral or earthy flavours.

The recent boom in highly hopped craft pale ales has only made the plant more important. "Hops pull an extraordinary amount of weight for our beers," says Thomas Nielsen, research and development manager at the Sierra Nevada Brewing Company in California and president of the US-based Hop Research Council. "I like to think it is the hops that are differentiating these products more than anything else."

But not all hops are born equal. Different varieties with picturesque names like Fuggles, Goldings, Citra, Hallertau and Saaz impart their own distinct degrees of bitterness or complex aromatics. Each prefers slightly different growing conditions. Then come the effects of local climate, soils, microbes and processing, together known as terroir, which brings subtle taste differences to hops, just as it does to a fine wine.

"Terroir is very important," says Ali Capper, a hop grower and director of the British Hop Association. The UK's mild maritime climate, for example, means hops have lower levels of a compound called myrcene, leading to beer with a more complex, delicate aroma. Those subtle differences can disappear in a bitterer beer, such as US-style pale ales. The UK brewing industry's increasing reliance on imported hops, rather than local varieties, to satisfy changing tastes is one reason why buying a round of beers in a London pub feels more and more like taking out a second mortgage.

But such developments are mere foam on the body of the problem. For all their ubiquity in beer, hops are particular about where they grow. "It's not a crop for the faint-hearted," says Capper. They need deep, high-quality soil, windbreaks to give shelter and plenty of moisture – but not too much, because that rots their roots. They are also highly sensitive to light. Flowering is triggered by the shortening of the days after midsummer, with the cones harvested in late summer. As the days close in further, the plant goes into a resting phase, dying back and storing food reserves in its roots for the next season. Without adequate cold over winter to encourage dormancy, growth during the following spring can be weak and unsynchronised.

This is why commercial hops are grown only in specific areas within a temperate "Goldilocks zone" between about 35° and 55° north. This includes the Pacific Northwest heartlands of Washington, Oregon and Idaho, which together account for about 40 per cent of global production, and areas of Germany, the Czech Republic and the UK. There is also some cultivation of hops at similar southern latitudes, in places like New Zealand.

It is also why climate change gets hop growers particularly hot and bothered. "No matter who you are or what you think, I don't think anyone in the industry is unaware of the climate situation," says Nielsen. In 2018, a report in *Nature Plants* raised fears that severe droughts and extreme heat could lead to hop shortages, causing the price of beer to shoot up still further.

ANDREW ERRINGTON/GETTY IMAGES

We are already seeing the first bit. In recent years, droughts in central Europe and the north-western US have hit hop harvests. "Hops are competing with Seattle and Vancouver for water from the mountains," says Capper. In 2020, a significant chunk of the Pacific Northwest crop was destroyed by intense wildfires in the region, or had to be rejected because smoke had tainted its flavour.

It isn't panic stations quite yet: covid-19 lockdowns reduced demand so much that there was actually a hop surplus in 2020. Many brewers also keep stores of hops that can last for years with the right care. But with conditions in traditional hop-growing areas predicted to worsen, the fear is that changes in climate and weather could alter the taste of the hops, their vigour or even, perhaps, wipe them out entirely in areas where they have grown for hundreds of years.

According to Colleen Doherty, a plant scientist at North Carolina State University in Raleigh, one effect is that nights are warming faster than days as global temperatures rise, reducing the number

BEER GOES SOUTH

Launched in June 2021, Gator Pale Ale is brewed using locally grown hops of the Cascade variety. So far, so US craft beer – only these hops were grown exclusively in Florida.

This was a far from trivial exercise, says Shinsuke Agehara at the University of Florida in Gainesville, who led the work. Hops are delicate flowers (see main story). "The high temperatures and hurricanes in Florida aren't ideal," he says. There also isn't enough of the daylight that is crucial during the summer months for hop flowering, which Agehara's team got around by attaching LED night lights at the top of the hops' support poles.

That isn't an entirely new idea: South Africa, another country outside the hop-producing "Goldilocks zone" in temperate mid-latitudes, also grows hops with help from artificial lights – originally because the country couldn't import hops during the apartheid era.

Florida's climate had other unexpected effects. Rather than a single crop of hop cones each year, there are two, one appearing from February to June, the next from June to November. The two crops together come to about 90 per cent of the average annual yield in the hop-growing heartlands of the Pacific Northwest. That's a boon, but most importantly the beer proved popular: punters described a pleasant, melon-like aroma.

Hops are checked after picking in Kent, UK

of winter nights where the temperature drops below freezing. This potentially influences the hops' crucial dormancy period and gives pests such as insects, bacteria and fungi more time to grow and attack plants. That can also affect hop flavour: some of the hoppy smell of beer comes from antimicrobial compounds produced by the plant as a defence against attackers.

One response is to create new, climate-resistant hop varieties. The breeding programme at Wye Hops in Kent, an English county that is a traditional centre of hop growing, is looking at between 3000 and 4000 varieties to find ones that will thrive in different conditions – for example, coping with milder, wetter winters and hotter summers. But there are limits to how far that goes. "No [hop] plant likes sustained heat of two or more weeks of 30°C plus," says Capper.

Similar projects are under way in the US, says Doherty – as are more dramatic initiatives (see "Beer goes south", opposite). But Capper for one thinks there may have to be a more fundamental rethink of hops' native territories. The UK should be OK, she says, as should New Zealand, because their maritime climates are less likely to see stark changes. But "I worry about Washington state, Oregon and Germany in terms of climate change," she says.

Hop growers may have no choice but to up sticks. "Michigan now has a small hop-growing area. The whole northern hemisphere industry is likely to go north" to Alaska and Canada, according to Nielsen – and also to extend its range in Australia and New Zealand in the southern hemisphere.

This wouldn't be unprecedented. While the European heartlands may have been pretty much unchanged for hundreds of years, "the US hop industry has a history of moving to get away from disease and pathogens", says Nielsen. "One hundred years ago, it was in upstate New York; 70 years ago, it was in California; 30 to 60 years ago, it moved to the Pacific Northwest. There is no guarantee it will stay there," he says.

That was mainly to escape mildew, a fungus that, once established in a hop-growing area, is nigh-on impossible to get rid of. Will climate change prove to be a more implacable foe? We can only hop for the best. ▮

Chris Simms believes in life, liberty and the pursuit of hoppiness

ROOTED IN HISTORY

The long history of flavouring beer with hops is just froth compared with how long we have been brewing: evidence of alcoholic drinks made from fermented grains dates back some 13,000 years. The first documentation of hop cultivation, by contrast, is from just AD 736 in what is now Germany. Before that, to give their drinks flavour, ale brewers used gruit, a mix of bitter herbs, flowers or roots, including dandelion, burdock, sweet gale, mugwort, ground ivy, yarrow, horehound and sage.

In the UK, hopped beer was probably first imported to Britain from the Low Countries in about 1400, and battled it out with native, unhopped ale for more than 100 years until a combination of taxes and laws gave hops the upper hand, turning ale and beer into synonyms.

One theory for the introduction of the Bavarian *Reinheitsgebot*, or purity law, of 1516 that mandated the use of hops in beer – and similar decrees in other parts of the Holy Roman Empire – was that gruit herbs were also used in pagan rituals.

The real breakthrough for hops, however, was probably the discovery of their preservative function: unhopped beer can go off in weeks, but boiling the hops before their use in the brewing process releases bitter, preserving resins that allow hopped beer to last for years.

Today, we have other preservatives – and gruit is on the rise again. More beers are now flavoured by botanicals other than hops, and an annual International Gruit Day is celebrated on 1 February, as more and more people go back to the roots.

Believe it or not!

Science throws up all manner of bizarre and outlandish discoveries. Test your knowledge of the world's weird side by picking out the strange-but-true from the stuff we made up*

MARTIN O'NEAL

**Some questions have multiple correct answers*

1 Health benefits of intimacy
A Cuddling increases bone density
B Sex is a nasal decongestant
C Masturbating improves eyesight

2 States of matter
A In condensed matter physics, a "hyperfluid" is a material with zero viscosity, meaning it can flow backwards in time and, when stirred, will spin forever (both forwards and backwards in time)
B In condensed matter physics, a "time crystal" is a state of matter in which the configuration of the component parts shifts in a repeating cycle forever without using any energy
C In condensed matter physics, an "ontological condensate" is an ultracold gas that could reveal the true nature of being, should we ever be able to isolate it

3 Hairy faces
A Beards might have evolved to keep faces warm
B Beards might have evolved to store food in through winter
C Beards might have evolved to soften the blows from punches

4 Animals at play
A Komodo dragons play tug of war
B Crows play blackjack
C Elephants play hide and seek

5 Celestial bodies
A Astronauts could use their own hair to create Martian space suits
B Astronauts could use their own blood to build a Martian base
C Astronauts could use their own nail clippings to create rocket fuel

6 Grand delusions
A Capgras syndrome is the irrational belief that a familiar person has been replaced with an exact duplicate
B Fregoli syndrome is the irrational belief that a familiar person, typically someone persecuting the affected individual, is disguised as various other people
C Cotard syndrome is the irrational belief that part of your body is missing or you are dead or don't exist

7 Living fossils
A Bunions are the only part of your body that fossilises while you are still alive
B Dental plaque is the only part of your body that fossilises while you are still alive
C Gall stones are the only part of your body that fossilises while you are still alive

8 Big data
A The Large Hadron Collider stores information on CDs
B The Large Hadron Collider stores information on floppy discs
C The Large Hadron Collider stores information on magnetic tapes

9 Self-improvement
A Walking backwards can enhance your short-term memory
B Doing a headstand for 90 seconds three times a week can boost your libido
C Pressing your temples and rubbing clockwise can increase your IQ

10 Alien weather
A It rains solid diamonds inside Uranus
B It rains liquid water on Venus
C It rains hydrofluoric acid on Mercury

11 Madcap maths
A In mathematics, the hairy ball theorem states that there is no non-vanishing continuous tangent vector field on even-dimensional n-spheres. In other words, given a ball with hairs all over it, it is impossible to comb the hairs continuously and have all of them lying flat

B In mathematics, the ham sandwich theorem states that, given n measurable objects in n-dimensional Euclidean space, it is possible to divide all of them in two halves with a single (n−1)-dimensional hyperplane. In other words, if you make a sandwich from bread, butter and ham, you will always be able to slice it to share all three ingredients equally

C In mathematics, the ugly duckling theorem is an argument showing that, if you assume a finite number of properties combinable by logical connectives and a finite number of objects, any two different objects share the same number of (extensional) properties. In other words, a duckling is just as similar to a swan as two swans are to each other

12 Emotional eating

A People feel angrier about inequality after eating hummus

B People find disgusting ideas more palatable after consuming ginger

C People become more interested in science after drinking tomato juice

13 Directionally challenged

A Honeybees prefer to turn right

B Honeybees always fly west when they first leave the hive

C Honeybees sometimes hitch rides on dragonflies

14 Extraordinary orifices

A Spiders can shoot cyanide out of their eyes

B Humans release alcohol through their ears

C Pigs can breathe oxygen through their rectums

15 Quantum weirdnesses

A In quantum physics, entangled particles transmit information faster than the speed of light

B In quantum physics, the exact position and momentum of a particle can't be deduced simultaneously

C In quantum physics, "virtual" particles can pass between parallel universes

16 Life on other planets?

A Astronomers have spotted "ogres" in the lakes on Saturn's moon Titan

B Astronomers have spotted "leprechauns" in craters on Mars

C Astronomers have spotted "elves" in Jupiter's skies

17 Dishonest males

A Lying men release volatile chemicals that smell like maple syrup

B Lying men mimic the body language of the person they are lying to

C Lying men only look to one side

18 Astronaut animals

A A tortoise has been to space

B A pig has been to space

C A porcupine has been to space

19 My mistake

A The pratfall effect means that people will like you more if they see you making mistakes

B The spotlight effect means that your mistakes aren't noticed by others as much as you think

C The Johnson effect mean that the more mistakes you make, the less likely you are to admit them

20 Amphibious applications

A In the 1950s, people used toad slime to treat their wounds

B In the 1950s, people used frogs as pregnancy tests

C In the 1950s, people used newts to help diagnose whooping cough

21 Molecular mischief

A Chemists have discovered that they could make novel molecules by throwing known molecules against the wall

B Chemists have discovered that they could make new molecules by having known molecules partially digested by a mongoose

C Chemists have discovered that they could make new molecules by singing Harry Belafonte songs to known molecules

22 Computer says what!?

A A wormhole has been created inside a quantum computer

B A time crystal has been created inside a quantum computer

C A quantum tunnel has been created inside a quantum computer

Quiz compiled by *New Scientist* staff

Answers

1 B
2 B
3 C
4 A
5 B
6 A, B and C
7 B
8 C
9 A
10 A
11 A, B and C

12 B
13 A
14 B and C
15 B
16 C
17 B
18 A
19 A and B
20 B
21 A
22 B

Razor sharp

Proposed by a medieval monk, Occam's razor remains the keenest tool for honing our world view, argues biologist **Johnjoe McFadden**

KIKI LJUNG

ON MY daily drive into work at the University of Surrey, I pass a road sign to Ockham. Perhaps a slight difference in spelling is one reason why it took me a surprising while to realise the English village's connection to one of the most fundamental concepts in science – I would argue, in my now more enlightened state, perhaps its most fundamental concept.

I am talking about Occam's razor. The creation of a 14th-century theologian with a racy life story, this is a principle often quoted as "entities should not be multiplied beyond necessity". It urges us to choose the simplest explanations or models for any phenomenon we observe. If you see moving lights in the night sky, say, think of known existing entities such as aeroplanes, satellites or shooting stars before considering flying saucers.

It has been a tool for scientific progress, not to mention a guiding principle for our own thoughts, right up to the present day. But I believe that modern science has rather lost sight of the simple fact that simplicity is the sharpest guide to greater truths.

Ockham is linked to Occam's razor by virtue of William of Ockham. Born in the village around 1285, William went to a local Franciscan school before being sent to Oxford to study theology, then known as "the Queen of Sciences". This title was largely due to the influence of Italian theologian Thomas Aquinas, who had recently Christianised the work of the greatest scientist of ancient Greece, Aristotle.

That mind-meld had supplied five scientific "proofs" of the existence of God, a variety of metaphysical essences of reality known as "universals", and diverse accounts of objects in terms of their ultimate purpose or *telos*. The purpose of acorns was to feed pigs, for example, while the purpose of pigs was to feed humans and the purpose of humans was to worship God.

Religious scholars of the time were assiduously dissecting the world into its plethora of universals, but when William arrived in Oxford, he was having none of it. He wielded his razor for the first time as he claimed these were all entities multiplied beyond necessity. He went on to insist that science and religion should never be mixed, because science is based on reason, whereas religion derives from faith. He was, I believe, the first person to so clearly separate science from its religious tethers, a move crucial to science's subsequent secular development.

These weren't universally popular innovations. They earned William a charge of teaching heresy and a summons to be tried before Pope John XXII in Avignon, in present-day France. His trial lasted about four years, but was never completed. William was forced to flee, chased by a posse of papal soldiers, after countercharging that the Pope himself was a heretic. He accepted the protection of the Holy Roman Emperor Louis IV of Bavaria, then in bitter dispute with the Pope, and spent much of the rest of his life writing what might be interpreted as mildly snarky treatises about the nature of political and religious authority.

His razor, meanwhile, acquired many devotees. Nicolaus Copernicus was one early adopter. Confronted with the "monstrous" complexity of the dominant idea that other astronomical bodies circled our planet, he declared in his *Commentariolus* of 1543 that the planetary motions "could be solved with fewer and much simpler constructions". That hunt for greater simplicity led him to the model of planets orbiting the sun. Johannes Kepler later discerned an even greater simplification, finding three mathematical laws of planetary motion applicable to all orbiting bodies – laws later explained in terms of Isaac Newton's laws of motion and gravity that were as valid on Earth as in the heavens. That confirmed William's own speculation some 350 years earlier that "It appears to me… that the matter in the heavens is of the same kind as the matter here below. And this is because plurality should never be posited without necessity."

The history of science is littered with similar stories of scientists allowing simplicity to guide them to greater understanding. But Occam's razor seems to have gone rather out

“Occam’s razor isn’t just a tool of science – it *is* science”

of fashion in today’s world of large data sets. That is even though it is embedded in one of our most powerful tools for dealing with them, one that is increasingly seen as fundamental to data-driven science: Bayesian inference.

Invented by Thomas Bayes – another religious man, this time a Presbyterian minister – in the 18th century, Bayesian inference is a tool that allows us to update a prior belief in a model, theory or explanation as new information comes in. Think of two dice, one six-sided and the other 60-sided. Suppose I throw one of these. I don’t tell you which, but reveal that it landed on a 4. You still don’t know which die I threw, but Bayesian inference provides a mathematical framework through which you can state that it is far more likely to have been the six-sided die (10 times as likely, in fact) – purely because there are many more other numbers that the 60-sided die could have produced.

Simple theories or models, such as Copernicus’s heliocentric solar system, are like the six-sided die: they make sharp predictions. Complex theories or models, such as Ptolemy’s model of everything orbiting our planet, are like the 60-sided die, making looser predictions that can fit a wider range of data. When we acquire information that fits with both simple and complex models, Bayesian inference, a mathematical embodiment of Occam’s razor, urges us to accept the simpler option because it is more likely to be the source of the data.

That goes against a grain in my own field of systems biology, which deals with modelling complex biological systems. The discipline has come of age since 2000, when the first draft of the human genome sequence was unveiled. At first, the promised new era of medicine informed by the knowledge of our genome seemed slow in coming. The finger of blame was pointed at the way biologists treated genes in isolation, rather than as components of complex, dynamic systems. My field galloped to the rescue by providing complex mathematical models of multiple genes and their innumerable interactions. But a problem then arose: where do you stop? Should models include 10 genes, 100, 1000, 10,000 – or the entire human genome?

My own interest in Occam’s razor was piqued about 10 years ago, when one of the founders of systems biology, my colleague and friend Hans Westerhoff, presented a seminar at Surrey entitled “No Occam’s razor for systems biology”. He argued that models of life’s workings needed to be as complex as possible to capture the high-level emergent properties that depend on interactions between genes and their products.

I have come to disagree. Although complex pathways and interactions certainly exist in living cells, unless we have evidence that their presence is needed to account for the data we see, we should eliminate them from our models: otherwise, we risk filling them with experimental noise. Together with my colleagues Katharina Nöh and Axel Theorell at the Jülich Research Centre in Germany, I am part of a team developing tools that apply the razor to slice through millions of candidate models of metabolism to find the simplest that work.

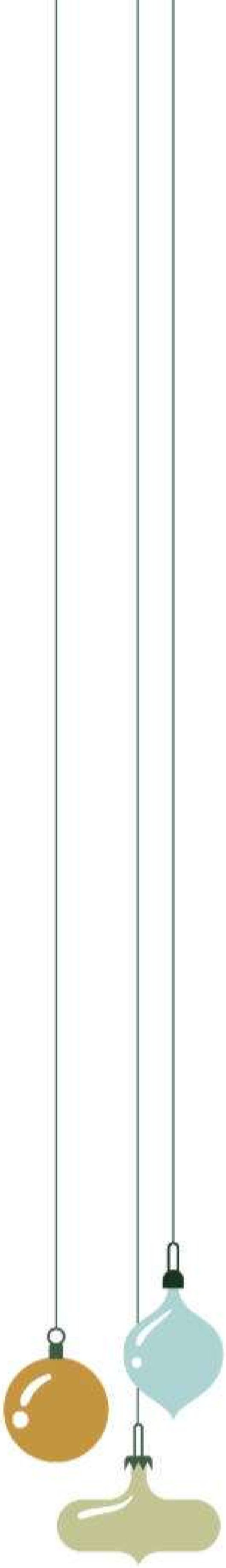
Truth in simplicity

My debate with Westerhoff and others continues, but my exploration of the impact of William’s logic has convinced me that Occam’s razor isn’t just a tool of science – it is science. Whether we are building bridges using Newtonian mechanics or employing our understanding of the genetic code to make covid-19 vaccines, science is essentially the search for the simplest models. To find them, and develop concepts and technologies from them, we use additional tools, such as experimentation, mathematics and logic.

But none of these tools is unique to science. Cooks experiment with new recipes, just as musicians experiment with harmonies, while mathematics and logic are as essential to accountants as they are to physicists. And using the tools doesn’t make something a science. Despite centuries of experimentation, alchemy didn’t develop into a science because its “theories” were junkyards of entities beyond necessity. Astrologers have wasted centuries using mathematics to make useless predictions.

Some people cite Karl Popper’s “falsifiability” criterion – that scientific theories can be disproved – as what distinguishes science from, say, religion. But as well as being equally applicable to many human activities, such as law, falsifiability doesn’t work. It is as impossible to disprove as to prove a hypothesis. The best we can do is compare the probabilities of rival hypotheses. And it is with that sort of thing that simplicity, as embodied in Occam’s razor, has always provided the best way. ■

Johnjoe McFadden is author of *Life Is Simple*, a book on Occam’s razor. He is still cutting edge



Why we laugh

Not being funny, but there is a lot more to laughter than joking around, finds **David Robson**

WHILE there is infection in disease and sorrow, there is nothing in the world so irresistibly contagious as laughter and good-humour." So wrote Charles Dickens in *A Christmas Carol*. He was in London in the 1840s, but these words ring true in any time or place. Laughter is one of humanity's few universal traits. Even in the time of covid-19, many people have found that a good chuckle has helped them cope with the stresses, uncertainties and interminable lockdowns.

It is surprising, then, that psychologists and neuroscientists were once reluctant to devote serious attention to laughter, with many believing expressions of mirth to be less important than those of unhappiness or despair. "Psychology still has a lot of catching up to do to balance out what is known about negative emotions with positive ones," says

DARIO MITIDIERI/GETTY IMAGES

Gina Mireault at Northern Vermont University.

This has been science's loss because recent results reveal that there is far more to laughter than you might think. Beyond the obvious connection with humour, it offers some truly profound insights into the nature of our relationships and the state of our health. The study of infant giggles may even help us understand how we develop our sense of self and the ability to read the minds of others. What's more, laughter turns out to be surprisingly common in other species.

Non-human animals aren't known for their sharp wits, but many do engage in play, often producing characteristic sounds to signal that their behaviour is friendly rather than aggressive. According to a review by Sasha Winkler and Gregory Bryant at the University of California, Los Angeles, published this year, scientists have documented these "play vocalisations" in 65 species. Most are mammals, but a handful of bird species are also known to signal their harmless intentions in this way. Kea parrots, for example, warble gently as they tussle on the ground or chase each other through the air.

In many animals, including chimpanzees, gorillas, rhesus macaques and dogs, play vocalisations take the form of fast, rhythmic panting. Cotton-top tamarins whistle. Rats emit an ultrasonic squeak beyond human hearing. And elephants make a kind of soft trumpeting noise. Winkler and Bryant speculate that such sounds represent a rudimentary form of proto-laughter that could have formed the evolutionary basis of our own humour. As Bryant puts it: "A phenomenon once thought to be particularly human turns out to be closely tied to behaviour shared with species separated from humans by tens of millions of years." Given its prevalence among primates, he estimates that proto-laughter evolved in one of our direct mammalian ancestors at least 100 million years ago.

Human relationships are much more complicated than those of the average mammal – and we have much more control over our voice. As a result, human laughter has evolved to be a potent and flexible social tool. According to Adrienne Wood at the University of Virginia, it serves three main purposes. The first is reward: when we laugh together, it shows appreciation of a particular behaviour and reinforces the interaction, so that we are more likely to act in the same way in the future. Spontaneous laughter triggers the release of opioids, which is probably what creates these rewarding feelings. Laughter's second function is to signal connection. These affiliation laughs tend to be voluntary (or "fake") and help to smooth over tension and embarrassment rather than reinforcing a particular behaviour. If you have said something potentially hurtful, for example, a polite chuckle might help to reassure someone that it was just playful teasing. The third purpose of laughter is to signal dominance – like when your boss laughs dismissively at your outlandish idea. Whereas a direct challenge, such as a cutting put-down, might trigger aggression, laughter indicates disapproval in a more subtle way. "It maintains a facade of social harmony," says Wood.

To provide evidence for this hypothesis, Wood and her colleagues asked 762 people to rate various samples of laughter on whether they sounded rewarding, reassuring (a sign of affiliation) or mocking (a sign of dominance). Each type was found to have different acoustic properties. The reward laughs were louder and longer. The affiliation laughs were quieter, shorter and mellower. The dominance laughs, meanwhile, lacked the pleasing melodic features of the others. "They were basically uglier and noisier and had all these acoustic markers of chaos," says Wood.

The conclusion that laughter is a powerful social signal chimes with findings by Bryant and his colleagues that participants could predict the closeness of people's relationships based solely on the sound of their guffaws, giggles and snide little titters. The laughers were all from the US, yet people from Europe, Asia and Africa were just as able to identify the nature of the laughs as fellow Americans were. People's capacity to tell whether a laugh is spontaneous or fake is also equally good across cultures. Other research has identified subtle differences in the ways that people laugh between cultures, but Bryant's results suggest that the core signals remain recognisable across the world.

"Laughter has evolved as a potent and flexible social tool with three key purposes"

Further evidence for laughter's universality comes from its early emergence in a child's emotional vocabulary. A baby's first laugh typically arrives by the age of 4 months – long before their first words. "It's the least complicated type of laughter because it's purely emotional, bubbling up from the limbic system, and it doesn't require control of the vocal track," says Mireault, who was inspired to study this developmental process by her own baby's helpless giggles at her brother sneezing.

As any caregiver knows, people will go to ridiculous lengths to tickle a baby's funny bone. In Wood's framework, these are reward › laughs, reinforcing the loving interactions. Mireault makes a similar argument, and points out that it brings obvious evolutionary benefits. "Laughter may serve as a kind of 'bonding agent' that keeps caregivers connected – in the loveliest way – to an infant," she says. "The infant subsequently benefits from having an engaged caregiver, both in terms of its physical survival and in terms of developing those critical feelings of attachment toward the caregivers."

> "Tickling could prime a baby's brain to acquire a sense of self"

Mireault's observations of parents and children suggest that it doesn't take long for babies to learn how to use the polite affiliation laugh. A 6-month-old playing peek-a-boo, for instance, may offer a muted giggle as it grows bored of the game. "It's using an effective social strategy," she says. By 8 months of age, babies are clowning around to amuse others. They are constrained by their clumsy movements and lack of speech, but their burgeoning humour involves making funny faces, imitating others and deliberate teasing, such as holding out a car key and then snatching it away before the caregiver can reach it.

Mireault thinks such behaviours show the early development of theory of mind – the ability to understand that others have their own thoughts and perspectives – which is generally not believed to blossom until several years later in a child's development. "When a baby attempts to tease another person, it reveals that the infant understands that it can influence what someone else is thinking," she says.

If that isn't profound enough, some researchers have suggested that tickling – one of the most common ways to elicit laughs in a baby – might be one of the first experiences that help infants acquire a sense of self. The argument is that we aren't ticklish to our own touch, only to someone else's, so these seemingly superficial interactions could prime a baby's brain to recognise itself as a unique body distinct from other things in the world.

Because laughter is so intimately linked with sociality, learning to laugh is a serious business. "If you can't join in with laughter, or you don't want to join in with laughter, or laughter straightforward irritates you – that will have a really big impact on the interactions that you have with people," says Sophie Scott at University College London. She and others have found that laughter is less contagious among boys at risk of developing psychopathy. Her team has also shown that people with dementia often struggle to identify the different types of laughter, and that this skill is particularly impaired in those with damage to the frontotemporal lobes, which is mostly associated with early-onset dementia.

These are early findings, but Scott thinks that the ongoing study of laughter will shed light on the development of these and many other psychiatric and neurological conditions, including depression. She also proposes programming apps to record people's laughter through their smartwatches or phones, providing a kind of "index" of someone's mental health that might be useful for healthcare providers.

Like many scientists studying laughter, Scott initially faced some resistance from colleagues who saw her research as unworthy of serious interest. She is now more convinced than ever of the profound insights it can offer for understanding the human condition. "Things that seem trivial and silly may actually be the most important elements of people's lives," she says. We may think of laughter as just a simple expression of humour, but it really is no joke. ▮

David Robson is having a laugh. His forthcoming book is *The Expectation Effect*

How to game laughter

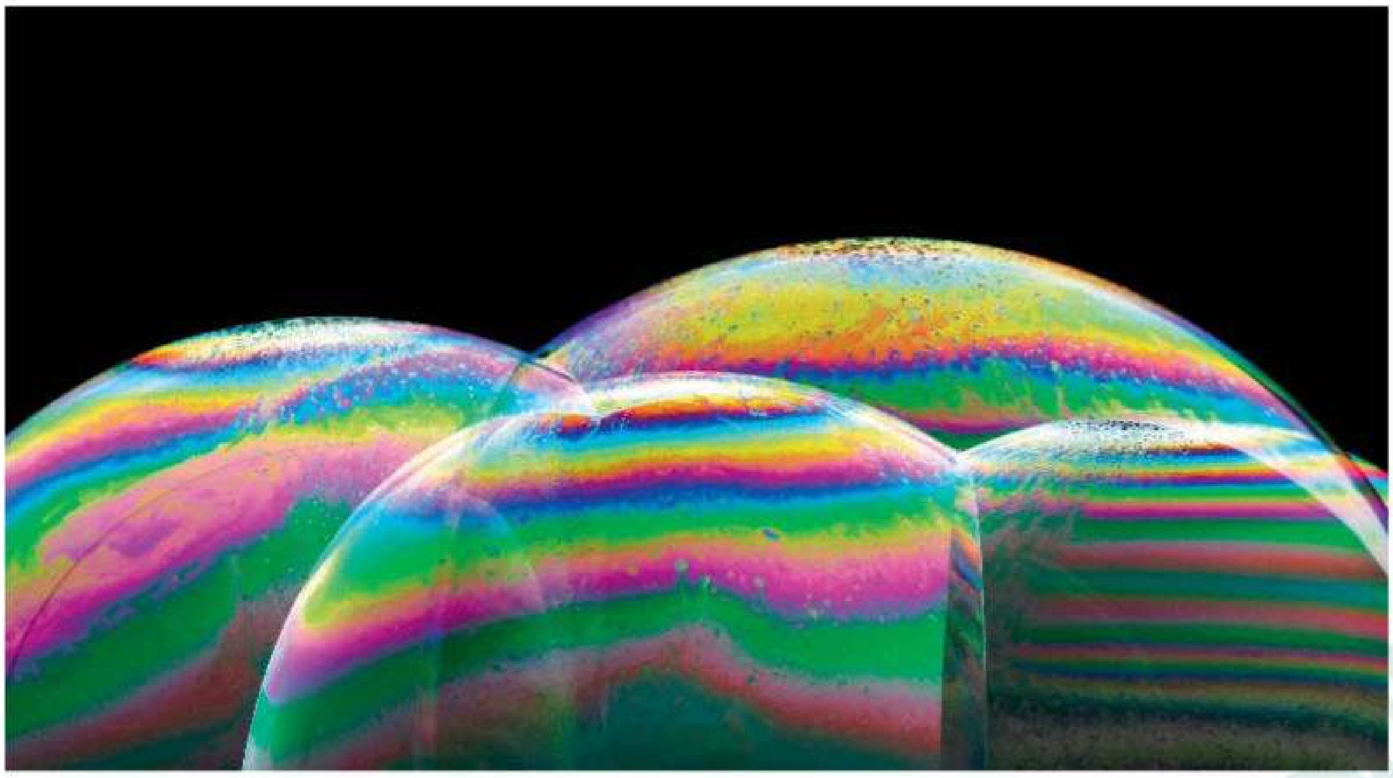
The idea that laughter is the best medicine may be something of a cliché, yet there is some evidence for its health benefits. A big belly laugh can exercise the heart, for example, and it works some of the trunk muscles as hard as traditional crunches. For fab abs, watch some classic comedy.

Given the importance of laughter in our social lives (see main story), you may also wonder whether you can use it strategically to boost your friendships or romantic relationships. A study across 21 societies revealed that, in general, people are able to tell the difference between fake and authentic laughs – but further experiments suggest that both kinds can increase someone's likeability. So, if you are typically po-faced, you might consider punctuating your conversation with some well-meaning chuckles to build a rapport with the people you meet.

Beware, though: people's perceptions of your laughter will depend on their existing opinions of you, and if they already find you irritating, it may just aggravate their annoyance. Instead, you might do better to look for situations that will allow you and your acquaintance to laugh spontaneously. One study found that people who watched a funny film together tended to open up afterwards, disclosing more personal information to each other. So, if you want to get serious with someone, get funny first.

FLASHPOP/GETTY IMAGES

A belly laugh is a good workout for your trunk muscles



FLAFABRI/ALAMY

A new hue

As we come to understand the secrets of iridescence in nature, we can harness this colourful phenomenon for a more sustainable future, finds **Michael Allen**

YOU dip a plastic wand into a mixture of water and washing up liquid and raise it to your lips. With a gentle blow, you unleash a stream of bubbles that bob about in the air, winking a swirling rainbow of colours back at you as they reflect the light. This is the beauty of iridescence.

You can also see it on the wings of birds and the shells of beetles. It is a completely different way of creating colour than the pigments and dyes we typically load onto brushes and into printers, one that is more subtle and adaptable. Now, we are starting to get a deeper understanding of iridescence. We are learning that animals make use of it in surprisingly varied ways, and it seems we could soon join them in harnessing this phenomenon to pull a few tricks of our own.

Most of us think we know the basics of how colour works. A ray of white light, composed of many different wavelengths or colours, strikes an object. Some of the wavelengths are absorbed by pigment molecules and the remaining ones are bounced back and seen as a particular colour. All this is true – but it isn't quite the full story.

Colour can also be produced by surfaces that reflect, or scatter, different wavelengths of light back in slightly different directions. This is what happens when we look at the surface of a bubble or a bird's wing and see that characteristic iridescent shimmer. If you move your eyes, the colour of the surface seems to shift and dance. The reflections are caused by tiny structures – bumps, hairs, ridges – on the surface that are somewhere around a billionth of a metre across.

We have known of iridescent structures in nature for a long time. Robert Hooke identified them in peacock feathers in the 1600s. Since then we have discovered that iridescence is responsible for the hues of many other living things. That includes insects, like jewel beetles, and parts of plants, like the marble berry, which looks just like a deep blue marble. There is even a mole with an iridescent coat.

More recently, we have learned that surface structures don't always produce that characteristic shimmering iridescence. Tiny structures on surfaces can also produce more ordinary looking colours – and they can be some of the darkest and brightest in the natural world.

In 2014, biochemist Silvia Vignolini at the University of Cambridge and her colleagues showed that the brilliant white *Cyphochilus* beetle from South-East Asia uses this structural effect to achieve its colour. Their scales scatter and reflect light more efficiently than any other known biological material. Since these beetles like to hide among a certain kind of white fungi, it isn't difficult to see why an ultra-white shell is handy. The secret of the insect's dazzling look seems to be that the tiny rods on the scales are of a very particular size. "We know that if structures are similar in size to the wavelength of light, then they can scatter the light," says Qingchen Shen, who is based at Vignolini's lab.

›

ANDY SANDS/NATUREPL.COM

A slime mould stores spores in iridescent structures called sporangia

The beetles' nanorods look white because they reflect nearly all light. But other structures can scatter light in a way that makes them appear intensely black. In 2018, Dakota McCoy at Stanford University in California and her colleagues investigated the wings of birds of paradise kept as specimens in museums and found that some have nanostructures that scatter nearly all light in this way.

The team found that a typical black feather reflects between 3 and 5 per cent of light, but when viewed from certain angles, the birds of paradise feathers reflected less than 0.3 per cent. Part of the work involved coating the feathers in gold dust, to make them amenable to analysis by electron microscope – and they still looked black even then. McCoy says this super-blackness helps set off the vibrant colours elsewhere in the birds' plumage, which they use to attract mates.

Beat the heat

Strange as it sounds, structural colour isn't just about colour. Because the size of the nanostructures involved determines the wavelength of radiation they affect, slightly larger structures scatter infrared radiation – otherwise known as heat – not visible light.

Nature hasn't missed this. Some butterflies are thought to use such effects to absorb heat and warm their bodies ready for flight. Other insects use it to beat the heat. Saharan silver ants scurry across the desert, where air temperatures can hit 50°C. A few years ago, we discovered that their bodies are covered in microscopic prism-like hairs that reflect almost all heat. This reduces their body temperature by a couple of degrees, helping them survive conditions in which other creatures perish.

In 2020, materials scientist Han Zhou at the Shanghai Jiao Tong University in China looked at a species of longhorn beetle that lives on active volcanoes in Indonesia, where ground temperatures can top 70°C. She found the beetle is covered in highly reflective prisms that keep it cool.

Inspired, Zhou wondered if she could design a structural colour coating that could be applied to buildings to lower temperatures. We already paint houses white for this reason, of course, as part of our quest to hit net-zero carbon emissions. But Zhou suspected that structural colour could perform better than regular white paint.

She developed a polymer film coated in microscopic pyramids and a random arrangement of ceramic particles. She says this mimics the effect of the beetles' nano-prisms and the coating reflects around 95 per cent of light. Zhou tested it by applying the material and a sheet of white paper to a car bonnet. She found that the snazzy new polymer kept the car about 5°C cooler.

> **"Iridescent materials can be made from almost anything"**

Others, including Shen and the team that discovered the secrets of the *Cyphochilus* beetles' scales, say they are also working on highly heat-reflecting structural materials. But would these really be better than white paint?

David Sailor at Arizona State University and his colleagues recently conducted a modelling study in which they compared the cooling effects of white paint, which is about 70 per cent reflective, with a supercooling coating that is about 95 per cent reflective. They modelled this across eight US cities and found that the reduction in demand for energy for cooling could be more than doubled when using the structural coating compared with white paint.

Structural coatings could also be more environmentally benign to produce. White paint often uses titanium dioxide as a pigment. "You usually extract it by melting rocks," says Benjamin Droguet, who also works in Vignolini's lab. "It is definitely not something which is good for the environment." Because their colour comes from structure, not specific chemicals, iridescent materials can be made from almost anything, including renewable materials like recycled plastic or cellulose derived from wood pulp.

An unexpected bonus of supercooling structural colour materials is that they don't have to be white. Not everyone wants a white building, and they can be so bright that they dazzle passers-by. The trouble is that conventional coloured paints absorb a lot of infrared radiation, so white is usually the best option by far for keeping cool.

To get around this, Yuan Yang at Columbia University in New York and his colleagues have developed a coating with two layers: one has an iridescent structure that reflects 90 per cent of infrared light, then regular coloured paint is added on top. Tests have shown that a black version can keep surfaces almost 16°C cooler than standard black paint.

Yang says the coatings work, though, in any shade or hue. The cities of our net-zero future will need to be cooler, but that doesn't mean they can't be as colourful as a rainbow. ▮

Michael Allen comes in any colour you like as long as it is read

When geckos play basketball

From reptiles to spiders, some unlikely creatures seem to have the ability to mess around. Why do they do it, asks **Michael Marshall**

AS I write, my kitten is having a funny 5 minutes – or rather a funny 2 hours and counting. A toy mouse has been thoroughly tortured and my laptop keyboard co-opted for a tap-dancing session.

It seems obvious to me that Peggy is playing, and that she is enjoying herself. We are used to the idea of certain warm-blooded creatures, especially our pets, larking around. But what about a crocodile toying with a ball or Komodo dragons playing tug of war with their keepers seemingly for the hell of it?

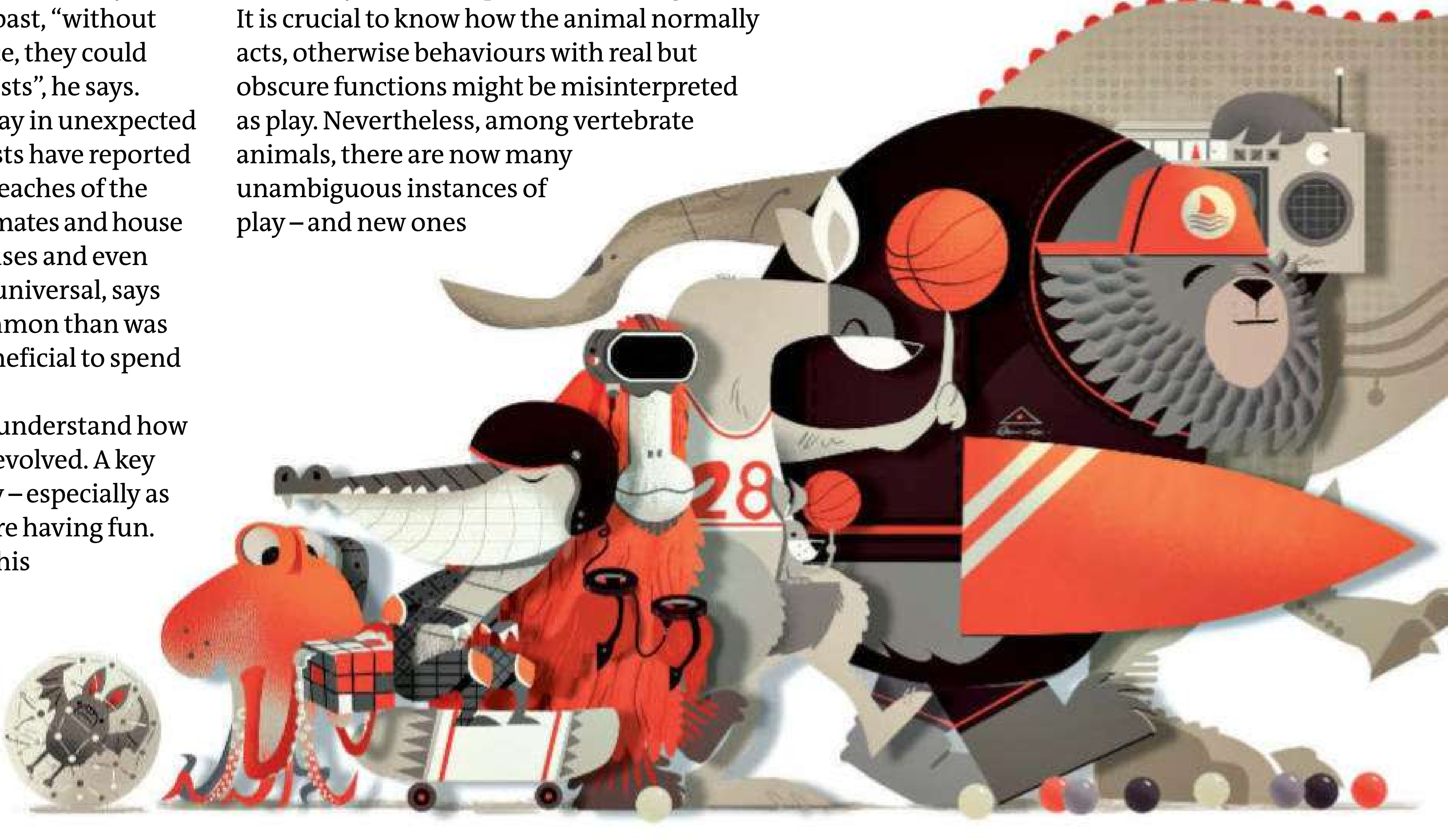
It could be that these animals really are playing – or that we are projecting our own playful nature onto their behaviour. "There's lots of anecdotal little stories out there," says Gordon Burghardt at the University of Tennessee, Knoxville. In the past, "without photographic or film evidence, they could be easily dismissed by scientists", he says. Today, though, evidence of play in unexpected creatures is building. Biologists have reported examples from the furthest reaches of the animal kingdom: not just primates and house pets, but reptiles, fish, octopuses and even spiders and wasps. Play isn't universal, says Burghardt, but it is more common than was once thought. So why is it beneficial to spend time mucking about?

To answer this, we need to understand how and why the capacity to play evolved. A key problem is how to define play – especially as we can't ask animals if they are having fun. Many thinkers have tackled this question, and Burghardt has attempted a synthesis of the various definitions. He devised five criteria for whether a behaviour counts as play. The action shouldn't achieve anything, at least not immediately: my kitten may attack her toy mouse, but she doesn't get any nutrition from it. It also should be voluntary, perhaps because it is enjoyable, and it needs to be different from the functional equivalent: when animals play-fight, they either don't bite or only do so gently. What's more, the behaviour must be repeated, and it only counts as play if animals do it when they are relaxed and sated, not hungry or fearful. "All five criteria needed to be met before I was confident that the behaviour we were seeing was play," says Burghardt.

This is a good definition, but assessing whether something is play or not still requires skilled judgement, says Isabel Behncke at the University for Development in Santiago, Chile. It is crucial to know how the animal normally acts, otherwise behaviours with real but obscure functions might be misinterpreted as play. Nevertheless, among vertebrate animals, there are now many unambiguous instances of play – and new ones keep being discovered, such as the play-fighting of grey mouse lemurs. Among birds, black swans have been observed repeatedly riding the crests of waves, like human surfers, while herring gulls seemingly play by dropping and catching objects.

But it isn't just warm-blooded mammals and birds that appear to enjoy mucking about. Perhaps the clearest example is the Komodo dragon, the largest lizard in the world. In zoos, they regularly play tug of war with their keepers over plastic rings. This isn't a form of hunting behaviour, because when the "toy" is covered in blood or tasty oil, the playfulness is replaced by possessiveness. Crocodiles, too, seem to enjoy playing. In 2015, Vladimir Dinets, then at the University of Tennesse, Knoxville, documented a host of different playful behaviours, including crocodiles repeatedly surfing down streams of water, toying with pink flowers and knocking balls around.

Most bizarre of all is a group of thick-toed geckos that were aboard the 2013 Russian BION-M1 space experiment in zero gravity. One of them wriggled out of its identity collar and the geckos proceeded to repeatedly nudge the floating object, whereas mealworms that drifted by were treated mainly with indifference. One individual was particularly playful. "We saw how one of the geckos, with an aimed push of the snout, throws the collar into a hole in the shelter, like a basketball into a basket," says Victoria Gulimova at the Research ›



GRAHAM CARTER

Institute of Human Morphology in Moscow.

In 2014, Burghardt and his colleagues even described an instance of fish playing: three male white-spotted cichlids started headbutting a thermometer in their tank, causing it to tip over and then right itself.

Still, vertebrates are only a small part of the animal kingdom. What about all the creatures that don't have backbones? We often think of inverterbrates as being simpler or more primitive than vertebrates, but this is a gross oversimplification – and evidence for invertebrate play has been accumulating for two decades.

In 1999, Jennifer Mather at the University of Lethbridge in Canada reported that giant Pacific octopuses seemed to play. In the lab, the octopuses fired water jets to make a floating bottle whizz around. In later studies, Mather found that common octopuses will also play with Lego bricks. She has recently used her play studies as part of a broader argument for advanced cognition in octopuses and other cephalopods.

Octopuses are one thing – we know they have complex brains, albeit quite unlike ours. What about insects? In 2006, researchers led by Elisabetta Palagi at the University of Pisa in Italy described play-like behaviours in paper wasps. When immature, the wasps performed exaggerated versions of adult dominance behaviours, which weren't combined with genuinely aggressive moves. They seemed to be play-fighting. "If we follow the definition [Burghardt's five criteria]," says Palagi, "we need to speak about play for paper wasps."

Similarly, in 2011, Burghardt and his colleagues described what they say is spider play. Juvenile male *Anelosimus studiosus* spiders performed mock courtship displays to juvenile females, and the pairs even engaged in mock copulations. "The females who have had that playful experience lay more eggs," says Burghardt, and the males that played are less likely to be killed or injured during courtship when the animals are sexually mature. So although the behaviour did appear to pay off in the long run, it didn't achieve anything at the time it was performed, so Burghardt argues that it fits his five criteria. Behncke, however, isn't so sure about this spider behaviour. "I don't think they play. Of course, I'm happy to be proved wrong," she says.

"If Komodo dragons and birds can play, maybe some dinosaurs did too"

According to Palagi, many researchers remain cautious about some claims of invertebrate play, but other examples have been broadly accepted. "Nobody has a problem to think an octopus can play," she says.

What is clear is that play is scattered like confetti over the animal family tree. But just because one species does this, it doesn't mean its closest relatives do. Behncke says this is because play doesn't evolve for one reason, but for many. "Some forms of play train more cognitive aspects," she says, whereas other types of play are more physical or social. That's why there is no simple pattern to which animals do it and which don't.

"Play enriches diversity of experience and, I think, enriches adaptation to complexity," says Behncke. The prediction is that you will see it in species that live in more complex niches, she says, meaning environments that are highly variable or unpredictable. This can include the social environment, for animals that live in complex groups.

For example, in a study published in October, Palagi and her colleagues showed that spotted hyenas spend a lot of time play-fighting. At first glance, this seems odd, because in hyena clans the dominant females are "extremely despotic", as Palagi puts it. However, these females also sometimes form alliances, and she thinks play-fighting may help cement these bonds.

The findings so far suggest that play didn't evolve just once, early in the history of animals. "If you look at the animal kingdom, very, very few species show the behaviour," says Palagi. Instead, it seems play arose independently in different lineages. But because so few species have been studied to see if they play, there is currently no way to tell how many times play evolved.

It may well be ancient. If Komodo dragons and birds can both play, it seems possible that some of their dinosaur relatives did, too. Sixty-six million years ago, maybe *Tyrannosaurus rex* enjoyed tug of war – pulling with its jaws rather than those silly little arms. ∎

Michael Marshall
isn't playing games

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Thursday 3 February 2022
6-7pm GMT/1-2pm EST and on-demand

What does it mean to have a healthy, happy brain? How can we prevent cognitive decline as we get older and maintain our mental wellbeing today?

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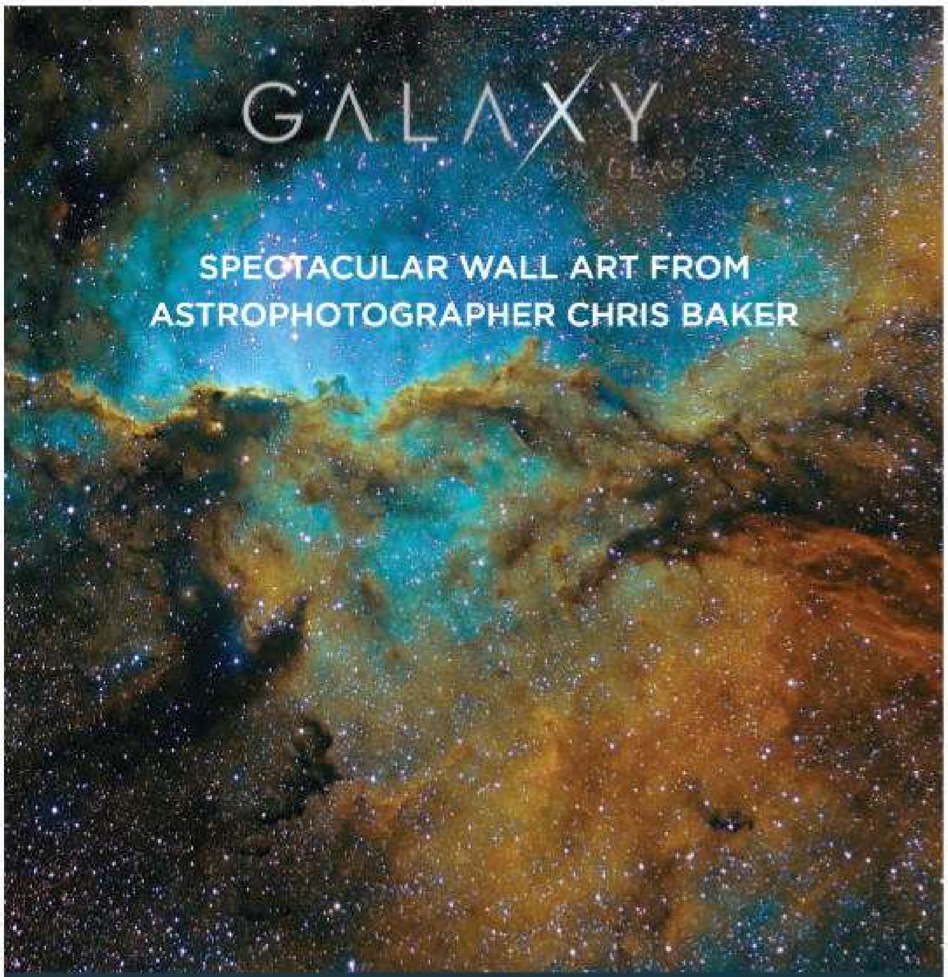

I would like to wish the New Scientist team and all the readers Season's Greetings and good health.
Chris Baker
www.galaxyonglass.com

I WOULD RATHER HAVE QUESTIONS THAT CAN'T BE ANSWERED THAN ANSWERS THAT CAN'T BE QUESTIONED
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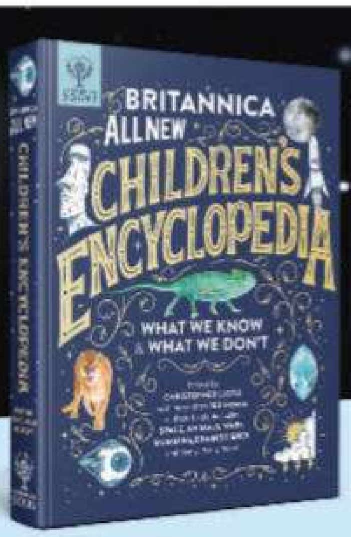
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Puzzle and quiz answers
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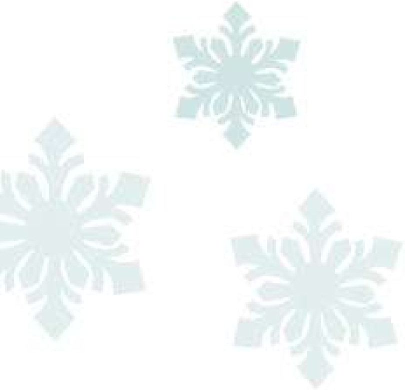
A look back at 2021 with our annual Feedby awards p88

Twisteddoodles for *New Scientist*
Picturing the lighter side of life p88



Citizen science

Snowflake spotters sought

The secrets of climate change are hidden in flakes of snow, but scientists need your help to classify them, says **Layal Liverpool**

Layal Liverpool is a science journalist based in Berlin. She believes everyone can be a scientist, including you. @layallivs

What you need

Access to Snowflake ID, via zooniverse.org

Paper and scissors for cutting out your own snowflakes (if the mood takes you)

BING CROSBY dreamed of a white Christmas. This December, I'm dreaming of categorising snowflakes. All in the name of science, of course.

White Christmas or not, you too can get up close and personal with snowflakes and contribute to climate research by taking part in the online Snowflake ID project. It invites volunteers to flick through high-resolution snowflake photos taken around the world – from Alaska to the Swiss Alps to Antarctica – and help classify them by characteristics, such as their size and shape. You can access the project via the Zooniverse citizen science platform.

Snowflakes come in many forms (see page 58). This makes them useful to climate scientists. The precise shape of a snowflake can provide information about the atmospheric conditions in which it formed and, in turn, about how Earth's climate is changing.

"Characteristics such as size, shape and density are important for accurate forecasting of severe weather and global climate change," says Annie McElvein, the project coordinator for Snowflake ID, which is run by the University of Utah.

At the same time, global warming is contributing to changes in snowfall patterns. "Arctic snowfall has diminished in recent years due to global warming, the temperatures are simply too high for snow to form," says McElvein. "Conversely, as the Arctic warms, some regions are cooling off." Indeed, there is evidence that global warming is contributing to changes in atmospheric wind currents that may lead to cooling and more intense snowfall in some areas.

MARIIA TAGIROVA/SHUTTERSTOCK

The project's customised cameras capture high-resolution photographs of falling snowflakes, from three different angles. These generate millions of images – far more than the Snowflake ID team can analyse themselves. Happily, more than 2000 volunteers have participated in the project so far, and their classifications are helping to train a machine learning algorithm to recognise and categorise different snowflake types automatically.

As a volunteer, you will be asked to spot key features of the flakes, such as little bumps on the snowflake surface called rime. These bumps form when a liquid cloud droplet is below freezing temperature and instantly freezes onto a snowflake that collides with it. The more rime there is, the more the particle resembles a fluffy snowball as opposed to a hexagonal star.

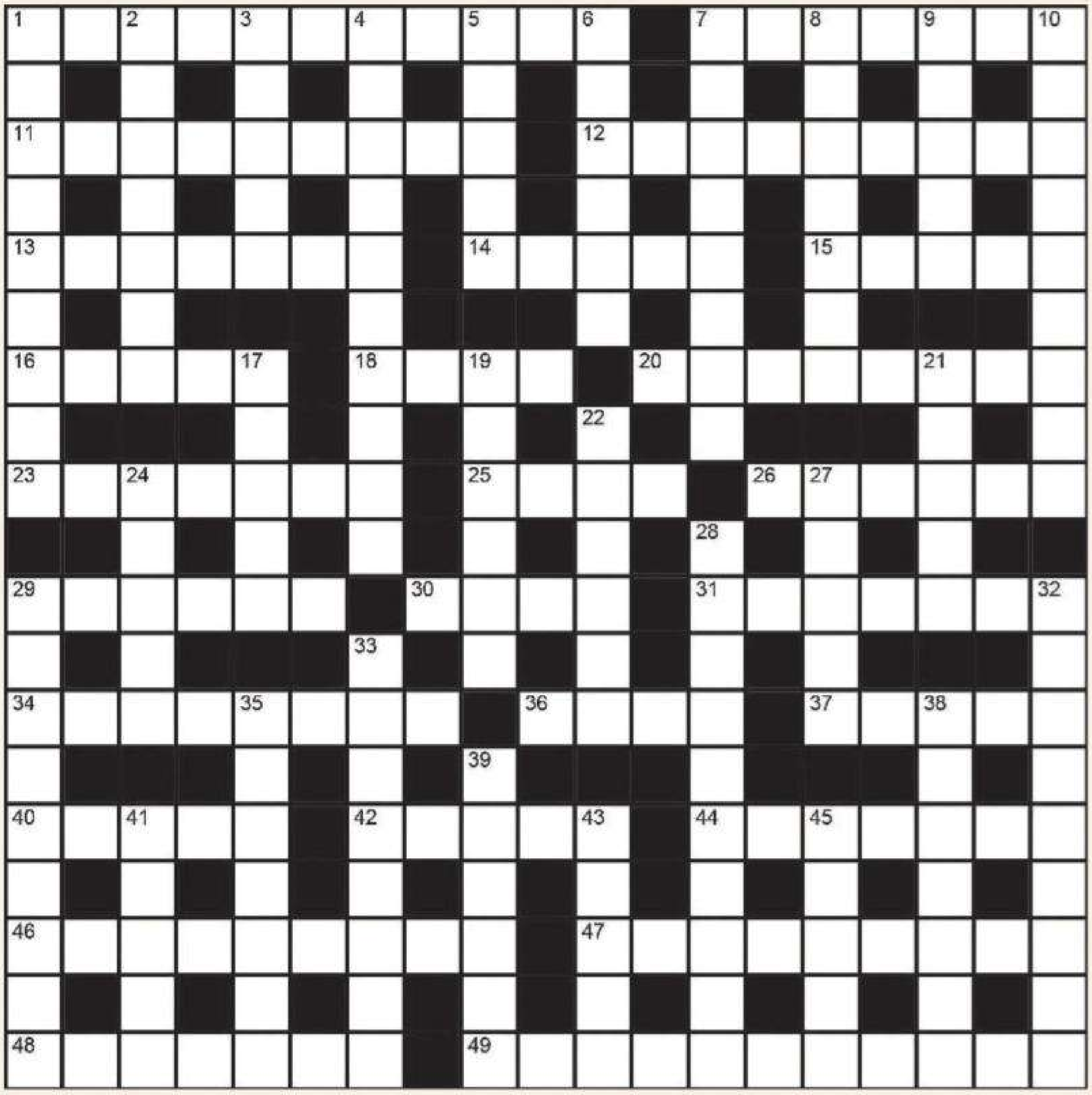
Learn more about snowflake structure and find instructions on how to cut out your own realistic snowflakes from paper by visiting the Snowflake ID web page. This and the rest of the project make for great holiday activities for snowflake enthusiasts young and old. As McElvein puts it: "This project is fun for anyone aged 8 to 80." ▮

These articles are posted each week at newscientist.com/maker

Citizen science typically appears every four weeks

Next issue
Stargazing at home

Cryptic crossword #73 *Set by Wingding*



Scribble zone

Our crosswords are now solvable online
newscientist.com/crosswords

Answers and the next quick crossword in the next issue

For a guide on how to solve *New Scientist's* cryptic crossword visit:
newscientist.com/cryptic

ACROSS

1 Dismantled jet car to see safety feature (7,4)
7 Sick pet carried by donkey – a high-tech mode of transport (7)
11 Cut limbs off politician after insult (9)
12 Fool limps badly, taking back message (9)
13 Wrap whisky in riding gear (7)
14 Physician high on ecstasy: "It grows on trees!" (5)
15 Jerks who are from US? (5)
16 Vote for keynote lecture to be trimmed (5)
18 Occasion when Bond hugs his boss (4)
20 Aircraft makes air go out turbulently (8)
23 Social media company captures hydrogen and neon gas (7)
25 Chinese leader right to retire and travel (4)
26 Bond parking next to narrow space (6)
29 Physicist's cat decapitated after gene partially blocked (6)
30 Split tree turned over with time (4)
31 Foolish to cross Skye, perhaps to deceive (7)
34 Peeress and winged creature spotted insect (8)
36 Fussy about opening (4)
37 Anti-authority figure born to appear in part of film (5)
40 Actor involved in sex trafficking (5)
42 From the beginning, good lighting engineers allowed moon to shine (5)
44 Medicine laureate initially fascinated by heartless rodent (7)
46 Executive officer and craft captured by alien in faraway world (9)
47 One giving directions incorrectly due to pigs (9)
48 Request main course without finishing all the starters (7)
49 Wearable gadget has vessels chasing unknown fish (1-3,7)

DOWN

1 Modern pest incompletely destroyed part of seed (9)
2 Catch some Lutherans needing lift (7)
3 Tranmere Rovers headers and goal show correlation (5)
4 Engineers rest diving equipment (10)
5 Listened to East Enders and made a mistake (5)
6 Cells of the same type are first to tackle problem (6)
7 Got off the ground with an air of superiority (6-2)
8 I see a fox score with pig losing tail (5-2)
9/19 Chemistry laureate and unfinished drink are what drives Bond? Quite the opposite (5,6)
10 Old TV part keeps icon working (9)
17 Find origin of Turkic people (5)
19 See 9 Down
21 Vin Diesel's partial to this music? (5)
22 Chemist and lecturer holds key (6)
24 Organised crime group sent up missile circling India (5)
27 Ray's an idle type, by the sounds (5)
28 Making stronger gin may flip cocktail (10)
29 Rising to record, study and inspect duck (9)
32 Entrusts tasks to representatives (9)
33 Fish? None caught in fishing equipment (8)
35 French article supports country scrapping Z – "it makes text more accessible" (7)
38 Alas, no tribe provides refuge for returning islanders (7)
39 Explosive damaged X-Men set, Magneto's heart cut out (6)
41 Brisk walk around university – this might come after rainbow? (5)
43 Two masters protecting good stuff found underground (5)
45 Injection increasingly became necessary, to some extent (5)

TATYANA/SHUTTERSTOCK

Festive puzzles

#144 Shaken, not stirred

set by Alison Kiddle

On special occasions, Grace enjoys a perfect martini with 6 parts gin to 1 part vermouth. Unfortunately, she has been gifted two bottles of ready mixed martini, one in a ratio of 5:1 and one in a ratio of 7:1, neither of which is to her taste. However, she has a measuring jug that measures multiples of 100ml, and an empty bottle.

How much of each blend should she use to create her perfect martini?

#145 Up the sprout

set by Rob Eastaway

My local greengrocer has a strange way of weighing produce. Vegetables go in a pan attached to a string that goes around a frictionless pulley and the pulley hangs from a suspended spring scale. The other end of the string is secured to the floor.

I picked out some sprouts for my Christmas dinner, at the bargain price of £1 per kilogram. The weighing scale indicated 1.6kg.

How much do the sprouts weigh? And how much do I owe?

#146 Meg's pegs

set by Colin Beveridge

Meg and Greg are playing a guessing game. Meg picks a code of four coloured pegs, each of which may be red, yellow, green or blue.

Greg's first, incorrect, guess at Meg's code is red-red-blue-green.

Meg tells Greg how many pegs are the correct colour in the correct place. She then tells him how many of the remaining pegs are a correct colour in the wrong place.

"Interesting!" laughs Greg. "In that case, I know your code."

What is Meg's code?

#147 Lebkuchen race

set by Steve Wain

A German company sells its festive lebkuchen in tube-shaped packs of 15 biscuits. Made with mathematical perfection, the diameter of each biscuit is exactly five times its thickness.

As I unpacked my shopping, I noticed two ants on the top rim of the pack I'd just bought. They set off at the same moment on what looked like a race. One marched along the length of the packet while the other, moving at the same speed, began on a circuit around the top of the packet.

Which ant finished first?

Answers to the festive puzzles, and the solutions to 11 December's puzzle and crossword, are on page 86

New Scientist never forgets

The past 12 months have been dominated by the threats from the covid-19 pandemic and climate change. But there was also lots of weird, wild and wonderful science and tech news. Can you recall these intriguing nuggets from our coverage in 2021?

1 In August, we learned that bumblebees (pictured) are better at foraging for nectar when given which substance?
A Methamphetamine
B Caffeine
C Cocaine
D Nicotine

2 In October, we visited Finland to see how it plans a bioeconomy that runs on wood. But which of the following wood technologies did we not report on this year?
A Transparent wood for energy-saving windows
B Extra-sharp wooden knives
C Posture-correcting stairs
D Electricity-generating floors

3 Which event millions of years ago may be responsible for determining the character of today's Amazon rainforest, according to a study we covered in April?
A Formation of the Sahara desert
B The Chicxulub asteroid impact
C Formation of Greenland's ice sheet
D The end of the last glacial period

4 In March, we reported on which unusual trait of the lungs of female American green tree frogs (pictured)?
A They sit outside the body
B They contain highly cancer-resistant cells
C They glow in the dark
D They can vibrate to cancel out other frogs' calls

5 How quickly can an elephant (pictured) suck up water in its trunk, as we learned in June?
A 130 kilometres per hour
B 280 kilometres per hour
C 400 kilometres per hour
D 540 kilometres per hour

6 It was revealed in July that a new type of DNA sequence had been identified. Which alien adversary from *Star Trek* was it named after?
A The Romulans
B The Borg
C The Klingons
D The Xindi

7 On the topic of aliens, according to estimates released in March, how many interstellar objects pass through our solar system each year?
A 1
B 3
C 5
D 7

8 In February, researchers proposed that Stonehenge (pictured) may have been rebuilt in Wiltshire after it was dismantled and moved from elsewhere in the UK. Which county could have been its first home?
A Pembrokeshire
B Monmouthshire
C West Sussex
D Devon

NORMAN LEE

9 In January, we were told that the efficiency of solar cells can be boosted by treating them with which chemical?
A Ethanol
B Capsaicin
C Psilocybin
D Cyanide

10 Research reported in November showed that a body-odour chemical that is released by people can make men calmer and women more aggressive. What chemical was involved?
A Methanethiol
B Putrescine
C Hexadecanal
D Hydrogen sulphide

11 In February, we learned that wood-eating cockroaches perform an unusual post-mating ritual. What is it?
A They spin on their backs
B They shed their ovipositors
C The female buries herself
D They eat each other's wings

12 Which country became the first to officially adopt bitcoin (pictured) as a national currency, a story we covered in September?
A El Salvador
B Panama
C The Bahamas
D Wales

13 A Tesla valve is a device that lets a fluid flow in one direction without requiring moving parts. The intestines of which creature were revealed in July to resemble this apparatus?
A Capybaras
B Sharks
C Cassowaries
D Wombats

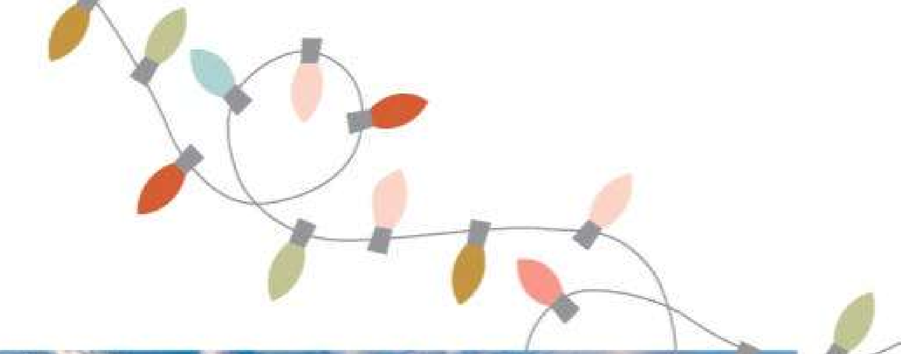
MANOJ SHAH/GETTY IMAGES

ARTUR MARCINIEC/ALAMY

ANTONY VAN DER ENT

14 In April, one of life's biggest questions was finally settled. Assuming it is served at 6°C, how many bubbles form in a half-litre glass of lager?
A 2 million to 10 million
B 200,000 to 2 million
C 50,000 to 150,000
D About 25,000

15 In May, the results of a cosmic census of the astronomical objects within 33 light years of our sun were released. How many stars



RIGHT: DONALD SLACK/ALAMY BELOW: AARON CELESTIAN, NHM LA COUNTY

> "One of life's biggest questions was finally settled"

COFFEYSHOTS/ALAMY

did it conclude are in this zone?

A 115
B 237
C 375
D 524

16 It has been a great year for research into artificial intelligence, but which of the following tasks has AI not helped us with in 2021?

A Telling us if cows are stressed
B Identifying us from our veins
C Improving robots' swimming
D Helping cats to show us affection

17 In October, researchers said they had identified where horses were first domesticated. In which modern-day country is this site?

A Mongolia
B Spain
C Russia
D Turkey

18 In November, we learned that a new mineral had been found in a diamond (pictured) from Botswana. What is the mineral called?

A Huttonite
B Davemaoite
C Oreskesite
D Lavoisierite

19 In April, we told you about a chemical code used to store a Jane Austen quote in plastic molecules. Which novel was the quote from?

A Mansfield Park
B Pride and Prejudice
C Persuasion
D Sense and Sensibility

20 In September, a newly discovered fossil dinosaur species on the Isle of Wight, UK, was given an unusual nickname. What was it?

A Infernal eagle
B Nightmare chicken
C Hell heron
D Pelican of doom

21 All sorts of unusual fossils have been unearthed this year. Which of the following ancient remains did we not report on in 2021?

A A rattlesnake in the jaws of a dead mastodon
B A turtle impaled on a branch
C A shark eating a proto-squid
D Two sea scorpions mating

22 How many pieces of debris smaller than 10 centimetres across are in Earth's orbit, according to our October deep dive on space junk?

A 100,000
B 250,000
C 400,000
D 500,000

23 In February, the mystery of what killed nine Russian hikers in the Dyatlov Pass incident in 1959 may have been solved. What did researchers say was responsible?

A A hurricane
B Infrasound-induced panic
C A slab avalanche
D A secret chemical weapons test

24 In January, we reported on hyperaccumulator plants such as *Phyllanthus rufuschaneyi*. What does the sap of this shrub (pictured) contain huge amounts of?

A Nickel
B Gold
C Frankincense
D Myrrh

Answers on the next page.
Quiz compiled by Bethan Ackerley

Quiz of the year
Answers

1 B – Caffeine
2 C – Posture-correcting stairs
3 B – The Chicxulub asteroid impact
4 D – They can vibrate to cancel out other frogs' calls
5 D – 540 kilometres per hour
6 B – The Borg
7 D – 7
8 A – Pembrokeshire
9 B – Capsaicin
10 C – Hexadecanal
11 D – They eat each other's wings
12 A – El Salvador
13 B – Sharks
14 B – 200,000 to 2 million
15 C – 375
16 D – Helping cats show us affection
17 C – Russia
18 B – Davemaoite
19 A – Mansfield Park
20 C – Hell heron
21 D – Two sea scorpions mating
22 D – 500,000
23 C – A slab avalanche
24 A – Nickel

How did you do?
18-24 Is that a stack of *New Scientists* we see beside you? Bravo! You clearly know your sciencey stuff.
12-17 The unmistakable whiff of knowledge is emanating from you. Congratulations.
6-11 Hmm. Feels like a heady combination of luck and educated guesses. Still, it is the taking part that counts, so well done.
0-5 Oops. Even guessing every time would have delivered six points, on average. Perhaps you require a *New Scientist* subscription in 2022!

#144 Shaken, not stirred
Solution

There is a trap to avoid here, as a 6:1 gin to vermouth ratio feels like it should be halfway between 5:1 and 7:1, but Grace tried mixing equal quantities and it tasted wrong.

The two bottles are 5/6 gin and 7/8 gin, respectively, and Grace wants a mixture that is 6/7 gin. That means 300 millilitres of the first bottle would have 250ml gin and 50ml vermouth, and 400ml of the second bottle would have 350ml gin and 50ml vermouth, which when mixed together gives 700ml of martini in Grace's perfect 6:1 ratio. Cheers!

#145 Up the sprout
Solution

The sprouts weigh 0.8 kilograms so I owe 80p. The scales are experiencing 0.8kg weight from the sprouts and a balancing 0.8kg from the tension in the string that is attached to the floor.

If you don't believe this answer, set up a pulley and a scale and test this out for yourself.

#146 Meg's pegs
Solution

Meg's code must be yellow-yellow-yellow-yellow. The only way that Greg can be certain of Meg's code is if Meg says Greg had zero correct colours.

For any other combination of correct colours and positions, there are at least two possible codes.

#147 Lebkuchen race
Solution

The ant walking the length of the packet won the race, because its journey was slightly shorter than that of the ant walking around the circumference of the packet's end.

If we call the diameter of a biscuit D, then the length of the packet is 15 x D/5 = 3D, while the circumference is $\pi D = 3.14$ D.

SHUTTERSTOCK/AFRICA STUDIO; SHUTTERSTOCK/INNAKREATIV

Cryptic crossword #72
(set on 11 December)
Answers

ACROSS 1 Stopcock, **5** Swab, **9** Pizza, **10** Spoke of, **11** Seethe, **12** Pupal, **14** Retort, **15** Pepsin, **18** Sisal, **20** Lurked, **22** Dungeon, **23** Dents, **24** Down, **25** Theremin

DOWN 1 Saps, **2** Ooziest, **3** Chanterelles, **4** Cashew, **6** Whelp, **7** Baffling, **8** Doppler radar, **13** Presided, **16** Sternum, **17** Flinch, **19** Sinew, **21** ISBN

#143 X marks the Spot
(set on 11 December)
Solution

The patio requires 196 white tiles and 29 black tiles. Here's why:

Suppose the patio is a $k \times k$ square containing a total of k^2 tiles. If k is odd we need $2k - 1$ black tiles and so $k^2 - 2k + 1 = (k - 1)^2$ white tiles (a square number); and if k is even, $(k - 1)^2 - 1$ (which is one less than a square). But no permutation of 1, 6 and 9 is one less than a square; so we are looking for a square for which k-1 is even. Of the three squares 169, 196 and 961 only $196 = 14^2$ is even; so $(k - 1)^2 = 196 = 14^2$ and $k = 15$. We need $2k - 1 = (2)(15) - 1 = 29$ black tiles and 196 white tiles to make a 15×15 square.

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2021, eh? While undertaking the end-of-year reordering of our extensive piling system, we are tempted to file the past 12 months under "see 2020". But leafing through our leaves with moistened forefinger, we find much to delight ourselves from this year as we dole out the Feedbys, the coveted annual Feedback awards.

New and shiny

As billionaires competed to get to space in 2021 (see page 24), those of us left on the ground got a feel for the high life thanks to "zero-gravity" chairs and beds that featured in our pages this year – the former with super-atmospherically super-useful UV-resistant mesh seating, the latter with anti-snore preset positions ensuring that, even if in space someone could hear you snore, they wouldn't.

We also discovered hydrogenated water, now the secret of Feedback's eternally fresh'n'young-looking skin. But our award for Innovation of the Year goes to a forward-thinking, digital addition to the personal grooming space: Nimble, "the world's first device that uses artificial intelligence to self-paint and dry nails in under 10 minutes". Feedback has four on order with a special telescopic applicator stick, for those rushed mornings when we need to look just fabulous.

Computer says wot?

Staying in the digital space, February brought us the story of Liam Thorp, a 32-year-old journalist based in Liverpool, UK, who received an urgent call-up for an early covid-19 vaccine. The assessment of Thorp's BMI as 28,000 kg/m^2 turned out to be based on interpreting his height of 6 foot, 2 inches as 6.2 centimetres.

But on the basis that human error might well have played a part here, Malgorithm of the Year goes to the Facebook photo-checking algorithm that found shots of a high-rise building, the England cricket team and a herd of cows overly sexual, and denounced a set of tramlines in Reims, France, for violating its ticket sales policy.

CHRISTMAS VECTOR GRAPHICS - BAUBLES:KN/SHUTTERSTOCK; HOLLY:KOSTENKO/SHUTTERSTOCK; SNOWFLAKE: YAVDAT/SHUTTERSTOCK

Twisteddoodles *for New Scientist*

I'VE USED SCIENCE TO ANSWER ONE OF THE GREATEST FESTIVE QUESTIONS OF OUR TIME!
IS IT "HOW DOES SANTA DELIVER TOYS TO SO MANY CHILDREN ALL OVER THE WORLD IN JUST ONE NIGHT"?
NO. MY WORK WILL SOLVE CONFLICT AND BRING PEOPLE TOGETHER
I'VE THE DEFINITIVE ANSWER TO "IS DIE HARD A CHRISTMAS MOVIE OR NOT?"
@twisteddoodles

Got a story for Feedback?

Send it to feedback@newscientist.com or New Scientist, Northcliffe House, 2 Derry Street, London W8 5TT

Consideration of items sent in the post will be delayed

A herring's throw

Ever-more inventive ways to explain 2 metres to people were a feature of 2020's Feedbys. This year, we are pleased to honour authorities in the Netherlands who combined social distancing with a vaccine incentive, by offering free portions of *Hollandse nieuwe* pickled herrings with a jab. And that is quite enough covid – for this year.

Poles apart

And so to Brexit. In a year when blaming global supply chain issues on Brexit and Brexit-related supply chain issues on global problems became a UK national sport, we doff our hat to the maker of "bipolar magnetic dog collars", which in April explained to reader Peter Holness that a monopolar version wasn't available due to "Brexit-related supply issues". End-of-year update: physicists hunting for magnetic norths *sans* souths at the Large Hadron Collider, a facility beneath an EU external border, are also still suffering persistent supply problems. Point proven, whatever it was.

Flame grilling

"nope. science itself isn't 'true' it's a constantly refining process used to uncover truths based in material reality and that process is still full of misteaks. neil just posts ridiculous sound bites like this for clout and he has no respect for epistemology". This tweet from frozen steaks manufacturer The Steak-Umm Company to astrophysicist Neil deGrasse Tyson came in response to his tweet "The good thing about Science is that it's true, whether or not you believe in it". A dual award for Social Media Takedown and Epistemological "Truth" of the Year.

Getting the measure

This year was, by any standard, the time it took Earth to orbit once around the sun measured against the fixed stars. Or possibly just 365 days. Or the time after which a fingernail would extend 1/30th of the distance around Earth's orbit, if nanometres were kilometres.

This was indeed the year of the bamboozling measurement unit. We had the baby boy whose length at birth was, said UK newspaper *The Sun*, almost 24 inches long, or "two footlong Subway sandwiches for perspective". We had *The Guardian*'s sterling efforts, including depicting Earth's annual heat absorption as the heat output of "630bn common household hairdryers blowing all day and night, 360 days a year" and a mass of sea cucumber excrement in multiples of the Eiffel Tower.

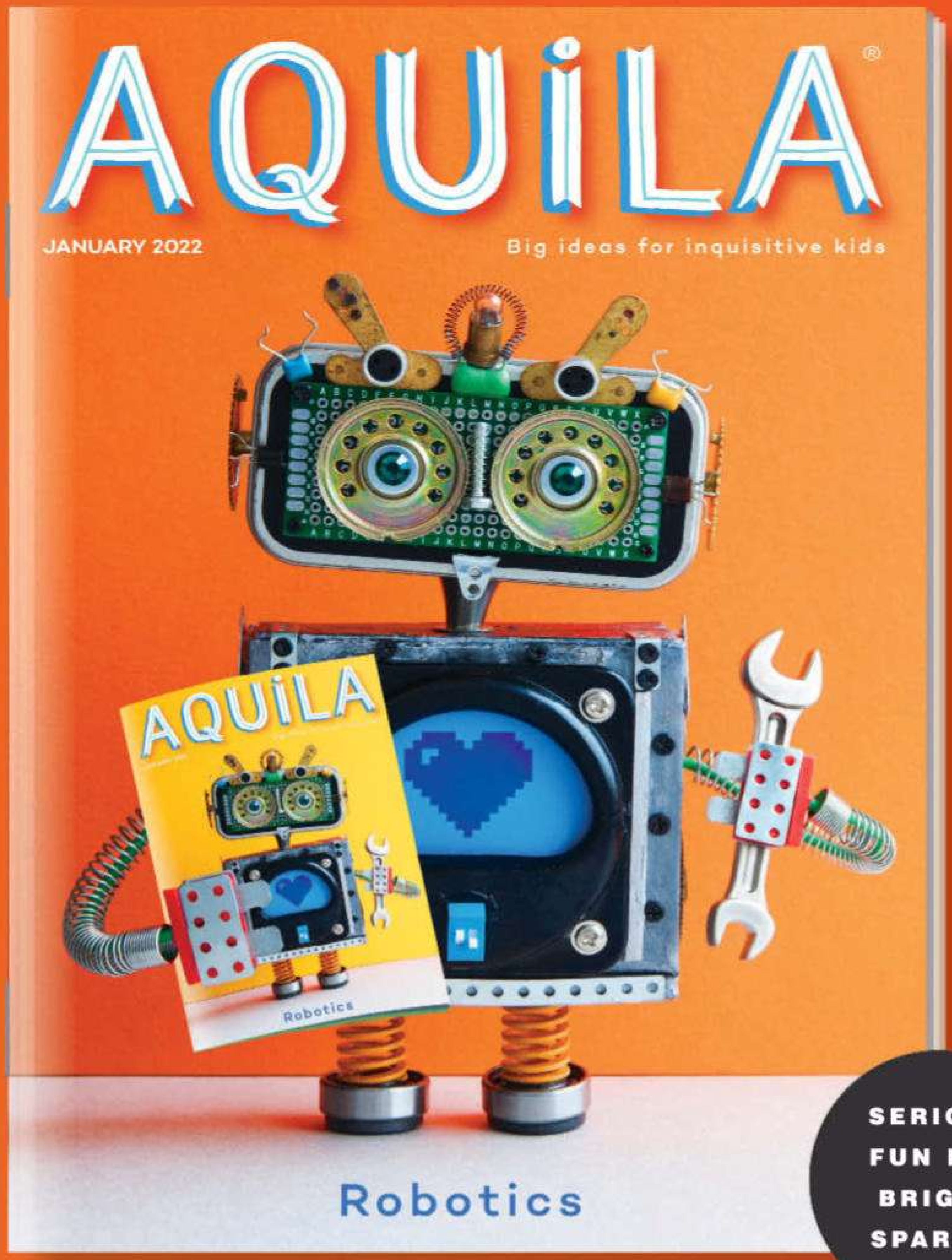
Special mention goes to a Colorado sheriff's office that tweeted about a road blocked by "a large boulder the size of a large boulder". But for sheer dedication to the cause of inexplicable explication, *The Wall Street Journal* wins Measurement of the Year by urging us to imagine an "adult African male elephant suspended from a rope that's the same diameter as a table tennis ball". It was about the tensile stress of tempered glass, natch.

Keeps popping up

It is tempting to grant our last award, for Person of the Year, to Keith Weed, whom so many of you were intent on informing us is the president of the Royal Horticultural Society. We make that his third mention, so instead the award goes collectively to you, our dear readers, for all the smiles and giggles in another trying year. A happy new year to you all, and see you for possibly too much more of the same in 2022. ▮

"...Advanced & Philosophical, Curious & Puzzling"

Richard Robinson, Brighton Science Festival



SERIOUS FUN FOR BRIGHT SPARKS!

GOOD ROBOT?

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